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EFFECTS OF ENVIRONMENTAL PROTECTION AND CONSERVATION POLICIES ON THE MINERAL SECTOR (INCLUDING CONSIDERATION OF AVAILABLE STUDIES BY CONCERNED ENTITIES OF THE UNITED NATIONS SYSTEM ON THE IMPACT ON THE ENVIRONMENT OF EXPLORATION AND MINING, AND REVIEW OF STATE-OF-THE-ART TECHNOLOGIES DEALING WITH PROCESSING OF MINING WASTES AND TAILINGS

Effects of changing environmental policy on the world mineral industry

Report of the Secretary-General

SUMMARY

The present report has been prepared, in response to Economic and Social Council decision 1993/302, on developments in environmental policy in the minerals sector. It analyses the evolution of environmental policy worldwide as well as the factors that influence mining industry responses. Special focus is placed on the relationship between environmental regulation and technological and organizational change leading to both improved competitiveness and environmentally sustainable mining practices.

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INTRODUCTION

1. The Economic and Social Council, in its decision 1993/302, and upon recommendation by the Committee on Natural Resources at its first session, held from 29 March to 8 April 1993, requested that a report regarding implications of environmental protection and conservation policies and strategies in the mineral sector be prepared for the Committee's second session. Specific topics to be addressed were legislative and regulatory changes, with an emphasis on technological innovation and greater efficiencies.

2. The present report concerns the effectiveness of environmental regulation. Growing environmental awareness worldwide has stimulated the development of a complex range of regulations and institutional mechanisms aimed at controlling the adverse environmental effects of industrial and agricultural production. The mining and minerals processing industries have been considered significant polluters and consequently have been the target of regulatory pressure. In this report, however, the sources of the environmental mismanagement problems that give rise to pollution in mining, particularly in developing countries, are examined, and the extent to which environmental regulation effectively deals with those problems is analysed. (In this report, mining is considered to cover the range of activities involved in exploring for, extracting and processing minerals to make metal products.) This report investigates whether there is a causal relationship between environmental regulation and the emergence of new environment-friendly technologies. It explores the complexity of that relationship, drawing on empirical evidence about the links between economic efficiency and environmental performance, and the determinants of environmental best practice. In order to analyse the effectiveness of environmental regulation, the report analyses its evolution in key metal-producing countries around the world and the extent to which, given its characteristics within each country, it is likely to lead to both environmentally sustainable and competitive economic development.

I. THE RATIONALE BEHIND EVOLVING ENVIRONMENTAL POLICIES

A. The need for environmental regulation

3. Prior to the late 1960s, the environment received little public attention and the response of Governments to "localized" pollution problems was generally to enact weak regulatory legislation that was poorly enforced. Sustained economic growth, however, produced higher incomes and a large proportion of the population in industrialized countries soon attained a reasonable standard of living. The public in those countries began demanding that Governments focus attention on removing some of the problems that had accompanied massive economic growth. From the late 1960s onward, therefore, clearer notions of the need to protect the environment and reduce pollution grew steadily in both developed and developing countries.

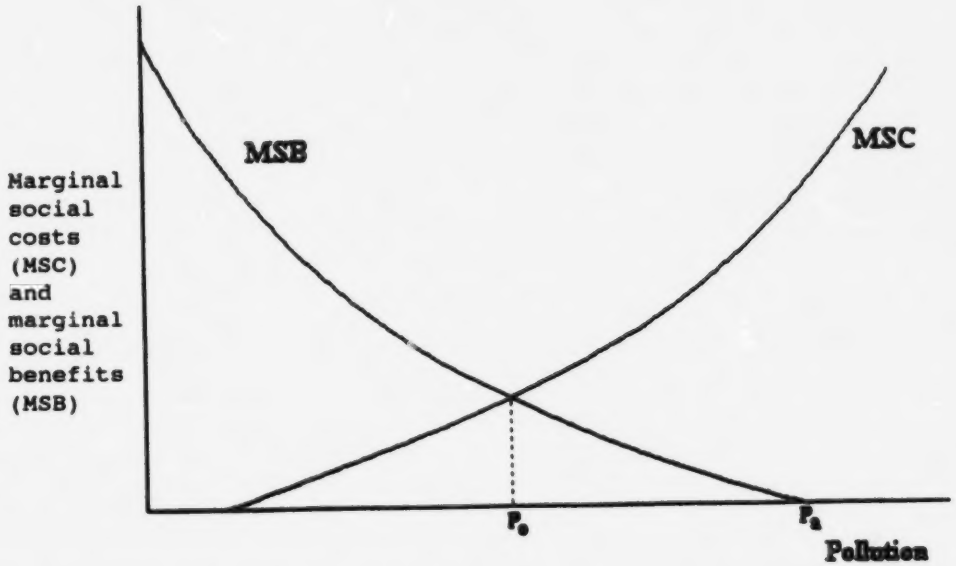
4. Recently, the environmental debate has been more concerned with the depletion and degradation of renewable resources, mainly water and air. Consequently, the term sustainable development was devised to reflect this

growing concern about the interaction between economic activity and environmental quality. (Sustainable development has been discussed in detail by many academics including Jacobs (1991); O'Riordan (1988); Pearce, Markandya and Barbier (1989); Pezzey (1989); Redclift (1987); and Turner (1988).) The 1987 report of the World Commission on Environment and Development, headed by Gro Harlem Brundtland, defined sustained development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987, p. 43). Implicit in the definition was the idea that economic policy should encompass environmental conservation and that its goal of achieving more equitable economic growth should refer to intergenerational as well as geographical equity (Jacobs, 1990). While leaders of the G7 group of industrialized nations adopted the principle of sustainable development at the World Conference on the Changing Atmosphere: Implications for Global Security (Toronto Summit), held in 1988 (see Jacobs (1991, p. 59)), a more global commitment to its aims was heralded at the United Nations Conference on Environment and Development (Earth Summit) held in Rio de Janeiro in 1992.

B. Discussion of environmental costs and their distribution

5. Conventional wisdom suggests that there are two types of costs incurred in industrial production (Tilton, 1992). First, there are those associated with production: labour, capital and material inputs. Second, there are those that the producing firm does not pay because they are external to the firm. These externalities include the costs of environmental damage such as ecological degradation, water pollution and air contamination. The primary responsibility of government environmental ministries has been to remove environmental externalities. One of the objectives of many forms of environmental regulation is to achieve environmental cost internalization. On the other hand, another key motivation for environmental regulation is the recognition that environmental quality is itself a public good. While mechanisms for handling environmental externalities in a perfect-information context have received some attention, regulators rarely have perfect knowledge and a broad range of articles in the literature have examined how imperfect information affects environmental regulatory instrument choice (Gruenspecht and Lave, 1989). This analysis further runs the danger of assuming that there is a fixed cost associated with each increment of pollution and that the reduction of this cost burden on society results in a corresponding incremental increase in the costs of production of the firm. Tilton (1992) describes this view clearly in his description of the relationship between the marginal social benefits (MSB) and the marginal social costs (MSC) of industrial production where pollution is an externality (see figure I). The argument rests on the assumption that the socially optimal use of an environmental resource occurs at a point where the additional benefits (in terms of the goods and services derived by permitting one more unit of pollution) are equal to the additional costs it incurs. In economic terms, this point is where the marginal social benefits equal the marginal social costs. If all social costs and benefits of pollution are incurred or internalized by the producing firm, it will have an incentive to pollute only up to a certain point (point P_o, in figure I). However, if the firm realizes all the benefits associated with pollution, but not the costs, it has an incentive to expand its production until the additional benefits from

Figure I. The marginal social costs and marginal social benefits of pollution



Source: J. E. Tilton, "Mining waste: the Polluter Pays Principle and US environmental policy", Working Paper, No. 92-8 (Boulder, Colorado, Colorado School of Mines, Department of Mineral Economics, October 1992).

generating a further unit of pollution are zero. Note that in this cir mstance, pollution has reached point P_1 which is far beyond the optimal point, P_0. The cost burden of this falls on society and the pollutee pays indirectly, although these costs may be absorbed to a degree by the State.

6. Furthermore, since consumers do not pay the full social costs of production, goods that are pollution-intensive in pollution are usually underpriced and the consequent market advantage means that they tend to be overproduced and overconsumed. It is then argued that this situation can lead to production inefficiencies since "free" environmental resources may be substituted for labour, equipment and other inputs (for which the firm must pay). For example, a firm may engage in the excessive and damaging use of water resources rather than incorporate a water treatment and recycling plant for liquid effluents. This in turn reduces the entrepreneurial capacity of the firm and, most importantly, acts as a disincentive to innovate. Such a sequence of events describes in part the historical decline of Bolivia's state mining firm (COMIBOL), and its related mismanagement of the environment (Jordan and Warhurst, 1992; Loayza, 1993). However, central to this concept is the idea that there exist fixed environmental costs, which can be either externalized or internalized. This report challenges such an assumption on the basis that it does not take into full account the implications of technological change and its potential to diminish the environmental costs of production.

7. Estimating the costs of natural resource degradation associated with mineral exploitation for the purposes of policy design is a complex task. The most significant problem is how to distribute those costs among polluter, State and community. Increasingly it is becoming apparent that such costs, particularly in the case of old and ongoing operations, are high. In the past, environmental costs were measured largely in terms of the expense involved in remedial treatment of degraded water quality, investment in environmental control technologies, or compensation for damage caused to local farm land by toxic dust. More recently, environmental costs have been estimated in terms of extensive rehabilitation programmes that transform the previous mine and plant site for alternative resource uses such as revegetation and leisure (Kopp and Smith, 1989). In the developing country context it has been argued that the mining industry was traditionally structured to externalize such environmental costs so that maximization of profit would be achieved, not so much through efficiency and innovation as through the appropriation of undervalued resources and the shifting of environmental costs onto others. When it comes to evaluating those costs, it should be remembered that those most affected by environmental pollution from mining in developing countries are generally those least able to understand and respond to it - remotely situated miners' families and isolated rural communities. Responses are typically short-term and "non-sustainable". For example, in the case of peasants whose farm lands were ruined through pollution from the Karachipampa tin volatilization plant in Bolivia, small compensation payments were offered to cover only the loss of particular harvests rather than the potential loss of those peasants' livelihood. In contrast, in the United States of America, the fastest-growing area of consultancy is that of assessment of natural resource damage liability, propelled by the "Superfund" laws; these laws apportion blame for environmental damage to any one of a mine's past owners, and charge that past owner with the

cost for the work, which the Government contracts in, of cleaning up and rehabilitating the damaged site.

8. Although some environmental degradation is the inevitable result of mining, examples can be given where pollution either has negative economic impacts or presents economic opportunities - for firms as well as Governments. For example, by-products that are toxic but could warrant economic reprocessing are frequently dumped. This is especially the case in developing countries, where inaccurate sampling or inefficient technologies result in such loss. Similarly, the mining of high-grade ore and the dumping of lower-grade ore, as a short-term expedient to boost foreign exchange earnings in times of crisis, result in greater environmental degradation (higher risk of acid mine drainage from dumps) and the loss of longer-term revenue. Costly water treatment projects are often implemented as part of the mine closure programme rather than (from the outset of the mining project) acid mine drainage prevention, which involves much cheaper pollution control and often results in the recovery of metal values. Finally, some firms have been obliged to pay the health-care costs of communities as a result of the drinking by those communities of degraded water; and in many cases such costs outweigh the cost of the technical change that would have been needed to treat the chemical effluents in the first place.

9. There is, however, considerable work still to be undertaken to quantify the nature and extent of, and the health risks associated with, environmental degradation caused by metals production. Currently there exist only isolated case-studies, and little systematic analysis of the problem has been undertaken. It is difficult to generalize since local geology, geography and climate affect mineral and ore chemistry, soil vulnerability and drainage patterns, and hence the extent of environmental hazard created. Furthermore, a major factor affecting the degree of environmental hazard is the social and economic organization of the production unit, which involves elements such as firm size, history and ownership structure, as well as its propensity to innovate. A discussion of those elements is central to section III of this report.

C. Command-and-control regulatory regimes: a general appraisal

10. Regulatory frameworks for safeguarding the quality and availability of land, water and air degraded as a result of mining and mineral-processing activities are growing in number and complexity. This has been the case particularly in the major mineral-producing countries of North America and Australia as well as in Japan and Europe. The norm in environmental regulation is that Governments set maximum permissible discharge levels or minimum levels of acceptable environmental quality. Such "command and control" mechanisms include best available technology (BAT) standards, clean water and air acts; Superfunds for clean-up and liability determination; and a range of site-specific permitting procedures which tend to be the responsibility of local government within nationally approved regulatory regimes. Moreover, those mechanisms tend to rely on administrative agencies and judicial systems for enforcement.

11. Three issues are particularly relevant regarding the appropriateness of such environmental regulation to reducing environmental degradation and improve

environmental management practices in metals production. First, there is a trend away from a "pollutee suffers" to a "polluter pays" principle. However, it remains the case that the polluter pays only if discovered and prosecuted; discovery and prosecution require technical skills and a sophisticated judicial system, and occur only after the pollution problem has become apparent and caused potentially irreversible damage. This highlights the tendency of such environmental regulations to deal with the symptoms of environmental mismanagement (pollution) rather than with its causes (economic constraints, technical constraints, lack of access to technology or information about better environmental management practices). That tendency can have serious consequences in some instances because once certain types of pollution, such as acid mine drainage, have been identified, it becomes extremely costly and sometimes technically impossible to trace the cause, rectify the problem and prevent its recurrence. Certain environmental controls may work only if incorporated from the outset into a project (for example, one of buffer zones to protect against leaks under multitonnage leach pads and tailings ponds). Second, BAT standards may be appropriate at plant start-up, but their specified effluent and emission levels are not necessarily achievable throughout the life of the plant. For instance, technical problems may arise and there may be variations in the quality, inter alia, of concentrate or smelter feed, if supply sources are changed. Moreover, there are serious implications for monitoring. It would also be erroneous for a regulatory authority to assume that standards were being met just because a preselected item of technology had been installed. Ongoing management and the environmental practices at the plant are also likely to be important determinants of "best environmental practices". Third (and related to points one and two above), BAT standards and environmental regulations of the command-and-control type tend to presume a static technology - a best technology - at any one time. This tends to promote incremental add-on controls in response to evolving regulation rather than to stimulate innovation, and acts in fact as a disincentive to innovation among equipment suppliers, mining firms and metal producers. Their innovation, which requires substantial resources for research and development, may be superseded through some regulatory authority's decision about what constitutes BAT for their particular activity. BAT gives the impression of technology's being imposed from outside the firm, not generated from within. The search for profit and cost savings tends to be a more obvious instigating factor of technical change. It might be argued that market-based mechanisms, a technology policy that is complemented by a regulatory framework and a good corporate environmental management strategy are more appropriate.

12. Environmental regulations designed specifically for mining and mineral processing have until recently been uncommon in developing countries, although most countries now have in place basic standards for water quality and, less commonly, air quality. A few developing countries have recently adopted extensive regulatory frameworks - sometimes replicas of older United States command-and-control models. This, for example, has been the case in Chile and, to a lesser extent, in Brazil. Growing concern about environmental degradation from mining activities is occurring during a period of rapid liberalization in developing countries that is finding expression in new policies to promote foreign investment, privatization schemes, and the availability of loan capital (Brown and Daniel, 1991). These conditions also influence the regulatory regime of developing countries. Should developing countries pose less onerous

environmental burdens on the potential investor to improve the terms of the investment? This would imply lower compliance costs or a greater assumption by the State of the environmental costs associated with mineral development projects. Should agreements be signed that release new investors from any liability for environmental damage caused by previous mine owners under less-restrictive regulatory regimes? Or will a clear and strict regulatory regime be more likely to facilitate credit flows from lending agencies that are increasingly more environment-conscious? Developing countries desperate for investment in their stricken mineral sectors will need to determine what the market can stand and how terms can be so structured as to reduce to the minimum the risk premium that the investor will seek for a given tax or regulatory burden (Morgan, 1992). It is worth noting that surveys by Johnson (1990) and Eggert (1992) imply that environmental policy has not been a major factor in determining the investment strategies of international mining firms. More recently, however, the industry press (Mining Journal, 30 October 1992) has been citing environmental regulations in Canada and Australia as a major causative factor in the delay and cancellation of potentially large investment projects and as a contributor to the shut-down of several mines. Moreover, evidence generated by the Mining and Environment Research Network (Acero, 1993; Gao, Wenmin and Xinhai, 1993; Hanai, 1993; Hollaway, 1993; Loayza, 1993; Nuñez, 1993) suggests that environmental regulation alone is unlikely to solve environmental problems in developing countries, owing to endemic production inefficiencies. In particular, the approach of State-owned enterprises to the environment reflects inefficient operating regimes, excess capacity, breakdowns and shut-downs, and poor management procedures, which are contributing to a worsening of the pollutant nature of effluents and emissions. Such inefficiencies make it highly unlikely that environmental controls will be incorporated effectively.

13. It has been argued that performance-related environmental standards are preferable to specification standards (or design specifications) as a stimulus to industrial innovation (Ross and Socolow, 1991). This is due to their perceived ability to allow greater flexibility with respect to the ways in which firms achieve their environmental goals. The major criticism of specification standards is that they discourage the development of creative innovations that might reduce pollution to levels below those for pollution emitted from required technologies or eliminate some forms of pollution altogether. Moreover, Crandall (1983) found that a significant fraction of specified pollution control equipment had not even been installed. Warhurst (1993) has criticized aspects of the "technology forcing" approach to environmental regulation by arguing that most firms will innovate for economic reasons and that frequently the most modern and economically efficient technologies will incorporate environmental advances. It is also risky for regulations to determine the direction of innovation's advance. Rothwell (1992) has further criticized the technology-forcing approach because it puts regulatory agencies in the difficult position of defining "appropriate technological feasibility". Poorly designed technology-forcing regulations, in his opinion, can discourage the development of promising new forms of technology.

14. Command-and-control environmental regulations require intensive monitoring to ensure that they are enforced. However, the sector of small-sized and medium-sized mines accounts for at least 25 per cent of mineral production in

many countries. Although individually those mines are relatively small polluters, collectively they account for a disproportionately large share of pollution. Such mines are often located high in the Andes or in remote tropical rain forests and are almost impossible to monitor systematically. Indeed, as regulation becomes more sophisticated, such monitoring requires skills and human resources that are far beyond the technological and managerial capabilities of many developing countries and frequently beyond their budget capabilities. Understanding the diverse range of toxicity and engineering issues behind regulatory aims poses challenges even in the industrialized countries. The most knowledgeable regulators are often head-hunted by the mining firms.

15. Finally, the enforcement of command-and-control regulations depends on a system that admonishes with imprisonment and fines. This in turn requires a legal structure and judicial system far beyond the capacity of most developing countries. Compliance is also limited, since fines are generally in an amount totalling but a fraction of the costs involved in remedial treatment and abatement technology. They are also only payable if the polluter is detected, and convicted. Inflation and local currency devaluation which are endemic in the developing country context also reduce the value of such fines. The costs of environmental regulation enforcement are generally hidden from the public eye and regulatory agencies are not generally accountable as such. Furthermore, the fact that different site-specific mining contexts often require individual regulation, perhaps for permit approval, provides opportunities for bribery which is endemic in bureaucracies and industry in many developing countries. It might be further argued that command-and-control regulatory instruments are unlikely to result in a reduction of pollution, since they cannot affect the capacity to implement technical change in a debt-ridden, obsolete and stricken mining enterprise within the developing country context. Such a firm might find it preferable to risk not being detected or convicted, to pay a fine or to mask its emission levels, rather than face bankruptcy through investing in radical technical change.

1. Polluter Pays Principle

16. The philosophical basis for most environmental regulation rests on the widely accepted Polluter Pays Principle. The Polluter Pays Principle attempts to deal with the issue of who should bear the cost of compliance with government regulation and clean-up of polluting activities. The essence of the Principle is that the polluter (often a firm) should be the first to pay for polluting activities - although it tends to pass on some or all of the costs to its customers. In the metals industry this is difficult since prices are mainly determined in independent end-markets. The application of this Principle may influence industrial technological change in several ways. For example, if pollution costs are deemed to be excessively high, then this may induce firms to invest in research and development aimed at reducing pollution. Spin-off effects such as the production of new marketable technology may be possible. However, some observers suggest that firms may seek to avoid pollution charges by relocating production activities to unregulated geographical areas. The pollution haven hypothesis will be challenged in Section III below. Environmental regulations also differ in the extent to which they force the development of new technological processes or products. It has also been argued

that the performance of environmental regulatory policy instruments depends more on the institutional framework within which they are used than on their technical characteristics. For a complete discussion of this point see Majone (1976).

2. Environmental liability

17. Environmental regulation based on financial liability is a relatively recent phenomenon which owes its evolution largely to the development of "Superfund" legislation in the United States. The Act governing Superfund allows the Environmental Protection Agency (EPA) (with the assistance of the States) to define potential or existing hazardous sites, design comprehensive programmes for their remediation (including clean-up and future pollution prevention) and, finally, to determine liability for the costs of implementing the remediation programme through the naming of one or more previous site owners or operators. A variety of legal means, both proactive and retrospective, are used to establish responsibility for unacceptable pollution and threaten financial redress if environmental clean-up or prevention is not undertaken. Environmental performance bonds are another common form of proactive liability instrument. Firms are required, in some areas, to post financial bonds prior to the beginning of their operations. Should they not meet agreed environmental conditions before commencement of operations, the bond can be cashed to pay for necessary clean-up. This mechanism is law in both Canada and Malaysia. Retrospective-liability instruments are used to establish liability for polluted sites used by one or more firms in the past. Usually, clean-up is undertaken using public funds, and then legal instruments are used to target and bill former owners/operators for the State's effort.

3. Emergence of market incentives

18. The issue of direct regulations versus economic incentives and disincentives is relevant in many areas of environmental regulation. Many economists, for instance, have argued convincingly in support of the increased use of so-called market mechanisms and the abandonment of direct standards approaches to environmental regulation. Essentially, economic incentives and disincentives attempt to allocate environmental efficiency through monetary markets. They attempt to recognize the market effects of environmental damage so that private producers are forced to absorb (or pass on to the customer) the social costs (in addition to the private costs) of production. Examples include pollution charges, emission offsets (specified sources of pollution permitted in exchange for reductions elsewhere), exchangeable or marketable pollution rights among firms or industrial sectors, negotiated discharge quotas, resource depletion quotas, resource depletion taxes, performance bonds requiring pollution reduction to obtain rebate, and subsidies for pollution abatement in exchange for investment in pollution-reducing innovation. A significant argument in favour of market mechanisms has concerned their potential for removing much of the burdensome political and administrative "baggage" (for example, uncertainty, wastefulness, excessive litigation) that presently encumbers many forms of direct regulation. Huppes (1988) has reviewed (and supported) this compelling argument in favour of financial instruments.

However, he has also pointed out the weaknesses that become evident when such instruments are introduced into administrative and political reality. Majone (1976) has found that most market mechanisms, while theoretically free of administrative complexity, have proved to be as subject to political and administrative "conditioning" and "bargaining" as other types of regulatory measures. So far there exists insufficient empirical evidence to evaluate the effectiveness of different market mechanisms.

19. Effluent (or pollution) charges are often considered (especially by economists) to be the best tool of environmental policy (Majone, 1976). In theory, the charge is set according to the marginal damage (cost) for each unit of pollution emitted. Polluters are then expected to decrease (through innovation or other means) their levels of pollution, so long as the marginal costs of doing so are less than the charge being levied. The optimum would be reached when marginal treatment costs (or costs associated with developing appropriate technologies for pollution reduction) equalled the pollution charge. Pollution charges also allow the State to build up a fund from which it can support environmental research and development as well as undertake publicly funded clean-up efforts. Jacobs (1991, p. 140) has noted that the charges levied in most of the currently operating effluent tax schemes are much too low to provide incentives for improving environmental performance. Rather, their primary purpose has been the raising of government revenue. However, one of the few charge schemes to be directed towards changing environmental behaviour, namely the Netherlands water pollution charge, has had considerable incentive effect on reducing emissions (Jacobs, 1991, p. 141).

20. Another preferred regulatory tool of environmental economists is the establishment of localized micromarkets in pollution permits. Dales (1968) first proposed, in 1968, the idea of establishing markets in pollution rights. In these, the Government sets an upper limit on a specific pollutant for a certain area (usually defined geographically) over a certain period of time. It then issues pollution permits or rights, which are basically licences allowing a certain emission level of the regulated substance. Polluters in the defined area are free to buy, sell or trade those pollution permits. Those innovative firms that reduce pollution may sell their pollution permits to heavier polluters for a profit. Government can exert an indirect influence over this process through its control of the permit market.

21. Theoreticians have argued that pollution permit markets provide an incentive for environmental innovation, since firms will receive monetary awards for technological innovation (Downing and White, 1986). However, it must be noted that theoretical models have also been developed that show that pollution permit trading may actually decrease the incentive to innovate relative to direct control methods of environmental regulation (Mauleg, 1989). Milliman and Prince (1989) analysed the effectiveness of five regulatory approaches: direct controls, emission subsidies, emission taxes, free market permits and auctionable market permits. They found that direct regulatory controls, free market permits and emission subsidies provided the lowest incentive to promote technological innovation. Emission taxes and auctionable permits were found to provide the highest incentive to innovate, as they rewarded the innovator with positive gains beyond the firm's own application of the technology through the benefits accrued from its wider diffusion to other firms. So far there exists

insufficient empirical evidence to evaluate the effectiveness of different market mechanisms.

4. Environmental impact assessment

22. Environmental impact assessment has become the most widespread form of environmental requirement for mining and metal-processing operations. Virtually all new mining operations must undergo some form of assessment before development and credit approval. Environmental impact assessment is valuable for pointing out possible negative impacts of mining on the environment. Alternative approaches, or remedial plans, can then be required as part of the mine permit requirement. Moreover, environmental impact assessment and mitigation plans are now standard in developing countries seeking financial assistance for mining projects. The World Bank and other international donor agencies and development banks will not provide credit unless satisfactory environmental assessments of the proposed project have been undertaken and acted upon.

D. Pollution prevention

23. Policy guided by the Polluter Pays Principle deals mainly with the results of environmental mismanagement - pollution - and its treatment once it has occurred. A new regulatory principle, Pollution prevention pays, aims to promote competitive and environmentally sustainable industrial production from the outset. By virtue of the requirement to reduce pollution at source, pollution prevention requires a priori that change be made to either the technology or the organization of the production process, or to both. This requires the development of new technological and managerial capabilities within the firm, technological alliances with equipment suppliers, and collaboration with research and development institutions. These elements may require in turn the design of new policy mechanisms that currently are not part of pollution prevention-type thinking. The reasons for this are rooted in the determinants of environmental management practices in the firm. Indeed, the evidence of empirical research undertaken by the international Mining and Environment Research Network suggests that the environmental performance of a mining enterprise is more closely related to its innovative capacity than to the regulatory regime within which it operates (Acero, 1993; Lagos and Valesco, 1992; Loayza, 1993; Gao, Wenmin and Xinhai, 1993; Warhurst, 1993). Capacity to innovate is, in turn, related to the entrepreneurial characteristics of the firm's management; its access to capital, technological resources and skills; and the broader policy and economic environment in which it operates. This evidence suggests that technical change, stimulated by the "Environmental Imperative", is reducing both production and environmental costs to the advantage of those dynamic firms that possess the competence and resources to innovate. Such firms include mining enterprises in developing countries, as well as transnational firms. However, the evidence is strongest for large new investment projects and greenfield sites. In older, ongoing operations, environmental performance correlates closely with production efficiency, and environmental degradation is greatest in operations working with obsolete technology, limited capital and poor human resource management. The development

of technological and managerial capabilities to effect technical change in such organizations would clearly lead to improved efficiencies in the use of energy and chemical reagents, as well as to higher metal recovery levels. Thus, improved production efficiency would result in improved overall environment management, including better workplace health and safety.

II. COMPARATIVE ANALYSIS OF DIFFERENT ENVIRONMENTAL REGULATORY REGIMES

A. Changes in standards regarding the environmental media of air, land and water

24. The present section reviews the evolution of regulatory regimes in key mineral-producing countries, while drawing on the preceding analysis of existing mechanisms. The history of regulation in many of those countries indicates that the mechanisms are cumulative and, inevitably, fall mainly within the command-and-control and Polluter Pays paradigms. Such incremental complexity leads to firms' perceiving the rules as constantly changing and tends to promote incremental "defensive" add-on technical change, rather than environmental management from the outset. The pollution prevention regulatory mode in effect represents a paradigm shift and so far has been initiated only in countries of North America, China and Ghana. These countries, like several developing countries, may have the advantage of developing a pollution prevention regulatory regime that can function independently of long-built-up and ineffective command-and-control regulation. However, this is in contrast to the fact that many developing countries have inappropriately copied United States regulations and proceeded in stages to regulate different environmental media, starting with water then air. More recently, ecosystem conservation, groundwater protection and rehabilitation requirements after mining have come to mean that regulation dealing with land and solid waste is also becoming increasingly important. This is a major focus of environmental impact assessment requirements for new project development and for environmental auditing undertaken by many ongoing operations.

B. Evolution of environmental policy and legislation applicable to mining in the United States of America

25. Environmental policy development in the United States has traditionally remained closely intertwined with concern for public health and safety. Early mining legislation was implemented and enforced at the state level. As environmental problems grew in political importance, however, a more comprehensive federal approach was necessary. 1/ In 1969, the National Environmental Policy Act (NEPA) was signed by Congress in an attempt to provide a systematic and coherent framework with which government could address environmental problems. The original legislation laid a basis for the future development of environmental regulations and empowered the establishment of the Environmental Protection Agency (EPA) as an independent regulatory enforcement branch of government. 2/ Today, the legislative branch of the United States federal Government has primary responsibility for the drafting and promulgation of environmental regulations. The state governments are primarily responsible for the implementation and enforcement of federal regulations. States can, and do, set environmental regulations that complement, or are more stringent than, those specified in federal legislation. State agencies are also responsible for issuing permits for industrial development projects, monitoring operations, confirming compliance with regulations, and disseminating public information. The major federal environmental statutes that affect mining activities in the United States are summarized in table 1.

Table 1. Legislative and regulatory controls applicable to mining in the United States of America

Type	Federal legislation and regulations
Command-and-control standards	Clean Air Act
	National ambient air quality standards (primary and secondary
	New source performance standards
	Clean Water Act
	Uniform effluent standards for discharges of specific toxic substances
	Safe Drinking Water Act
	Maximum contaminant levels for various minerals in drinking water
	Resource Conservation and Recovery Act
	Subtitle C regulations for hazardous mine-processing wastes
	Subtitle D regulations for non-hazardous mine wastes (proposed)
	Surface Mining Control and Reclamation Act
	Permit-based regulations for returning mined site to baseline characteristics
Market-based legislation and approaches	Clean Air Act
	Lead emissions trading programme
	Sulphur dioxide emissions trading (a likely possibility in the future)
Liability legislation	Surface Mining Control and Reclamation Act
	Abandoned mine reclamation fund

Type	Federal legislation and regulations
	Forest and Rangeland Renewable Resources Act
	Posting of a reclamation bond for mining activities on forest services lands
	Comprehensive Environmental Response Compensation and Liability Act
	Establishing liability for abandoned mining operations
	Contribution to the Superfund
Permitting and environmental impact assessment legislation (or process)	National Environmental Policy Act
	Preparation of an environmental impact statement (EIS) for any mining project that takes place on federally owned land, including exploration or road construction
	Preparation of an EIS for any project requiring federal permit
	Clean Water Act
	National pollutant discharge elimination system: requires mines to comply with effluent limits defined by EPA for each pollutant specified in the granted permit
International	Canada/United States Clean Air Agreement

C. Evaluation of environmental policy and legislation applicable to mining in Canada

26. Although the responsibilities for environmental regulation of natural resource-based industries lie mainly with the various provincial Governments, federal and provincial jurisdictions in this area overlap to a considerable extent. 3/ The federal Government has responsibility for all management aspects pertaining to the Yukon and Northwest Territories; environmental assessment of development projects involving the use of federal agencies, lands or funds; environmental protection against toxic substances; negotiation of international environmental agreements; and protection of navigable waters and waters occupied by fish or fish habitat. The provincial Governments retain primary responsibility for undertaking environmental assessments of proposed development

responsibility for undertaking environmental assessments of proposed development projects; protecting provincial waters against pollution; controlling and permitting the development of natural resources; and implementing air quality requirements negotiated by the federal Government. Table 2 summarizes Canada's environmental regulation as it affects mining and metal processing.

Table 2. Legislative and regulatory controls applicable to mining in Canada

Type	Federal legislation and regulations	Provincial legislation and regulations a/
Command-and-control standards	Fisheries Act	Environmental Protection Act
	Metal mining liquid effluent regulations and guidelines	Municipal/industrial strategy for effluent abatement
	Canadian Environmental Protection Act	Monitoring regulations and emission-level regulations
	Asbestos mines and mills release regulations	Countdown acid rain regulations
	Secondary lead smelter release regulations	Air management strategy regulations (being developed)
	Priority substances list regulations (subject of negotiation at present)	Ontario Water Resources Act
Market-based legislation and approaches	Consideration of emissions trading for air quality: negotiations with provinces	
Liability legislation	Territorial Land Act	Mining Act
	Territorial land-use regulations: posting of bonds for reclamation based on negotiations	Bond posting for reclamation and liability clause to sue for financial compensation

Type	Federal legislation and regulations	Provincial legislation and regulations a/
Permitting and environmental impact assessment legislation (or process)	Territorial Lands Act Territorial land-use regulations Navigable Waters Protection Act Canadian Environmental Assessment Act Requires environmental impact assessment for projects involving federal funds, federal lands or federal staff	Mining Act Environmental Assessment Act Planning Act Public Lands Act Parks Act
International agreements	Canada/United States Clean Air Agreement	Implementation of the Clean Air Agreement provisions

a/ Examples in this table are taken from the Government of Ontario.

D. Evolution of environmental policy and legislation applicable to mining in Australia

27. Environmental control over mining activities in Australia is, to a large degree, a responsibility of the State and territorial Governments rather than of the federal (Commonwealth) Government. 4/ Environmental legislation applicable to mining, unlike that in North America, varies little from State to State, 5/ although New South Wales (NSW) has the most comprehensive and stringent regulation in Australia. The project approval processes, which now incorporate environmental impact assessment, have resulted in adjustments in the way that Australian mining projects are currently developed (Cox, 1992, p. 4). Recently, the amount of legislation pertaining to the environmental impacts of mining operations has grown considerably as a result of public pressures. Table 3 summarizes environmental legislation applicable to mining and metal processing in Australia.

Table 3. Legislative and regulatory controls applicable to mining in Australia

Type	Federal legislation and regulation	State legislation and regulations a/
Command-and-control standards		Clean Air Act
		Clean Water Act
		State Pollution Control Commission's Enabling Act
		Noise Control Act
Liability legislation		Mining Act
Permitting and environmental impact assessment legislation (or process)	Environmental Protection (Impact of Proposals) Act	Environmental Planning and Assessment Act
	National Parks and Wildlife Conservation Act	National Park and Wildlife Act
	Resource assessment Commission Act	Mining (Access to Lands) Amendment Act
		Clean Air Act
		Clean Water Act
		State Pollution Control Commission's Enabling Act

a/ Examples in this table are taken from the Government of New South Wales.

E. Environmental regulations applicable to mining in the European Community

28. The European Community (EC) currently determines the most important aspects of environmental legislation applicable to mining operations in member States. EC Directive No. 85/337 requires the consideration of environmental effects at the earliest possible stages in member state government decision-making. Environmental assessment of proposed mining projects is also required prior to approval. Member States have flexibility in determining what criteria are to be incorporated into assessments and what special conditions are to be attached to project approval processes. EC regulations require mining and smelting firms to be licensed prior to operation. Emission values have been set for emissions of specific heavy metals and dust. However, legally binding national emission limits have been set only in Germany and Spain. Guidelines exist in the United Kingdom of Great Britain and Northern Ireland and Italy. Table 4 summarizes selected details of environmental regulation affecting mining and metal processing in EC and certain member States.

Table 4. Environmental regulations applicable to mining in the European Community

Type	European Community regulations	Member States regulations
Command-and-control standards	EC Directive on Air Quality Limit Values and Guide Values for Sulphur Dioxide and Suspended Particles (EC 80/779) established limits for air pollution that were required to be implemented by all member States by 1 April 1993	Great Britain Clean Air Act (1956 and 1968) Control of Pollution Act (1974) Water Act (1989)
	Heavy metal and dust licence requirements for non-ferrous roasting and sintering plants with capacity greater than 100 tons/year	Health and Safety Work Act (1974) Emission into Atmosphere Regulations (1983)
	EC Directive on the Protection of Groundwater Against Pollution Caused by Certain Dangerous Substances (EC 80/68) was established in 1980. Contains lists I and II of substances to be controlled	Environmental Protection Act (1990): integrated pollution control implemented by Her Majesty's Inspectorate of Pollution
Permitting and environmental impact assessment legislation (or process)	EC Directive No. 85/337 requires environmental impact assessment of new mining projects in member States	Environmental Protection Act empowers local planning authorities to assess the potential environmental impacts of new mines before licensing
	Best available technology not entailing excessive costs (BATNEEC) to be incorporated into development plans before they are authorized	Ireland Irish Environmental Protection Agency issues licences that specify the conditions governing environmental performance at the mining site. Can require the "retrofitting" of environmental controls to existing mine sites
Market-based legislation and approaches	Eco-Management and Auditing Regulations (EMAS) will provide for environmental accreditation, preferred environmental status. This can be considered a market incentive to improve environmental performance	Germany, France, Italy the Netherlands Water pollution effluent charges. Revenue raised used for improving water quality, reducing pollution
		Great Britain British standard (BS) 7750 will require that a firm (and where appropriate a mining site) have an environmental policy that is publicly available, sets clear environmental objectives and is committed to continuous environmental improvement

F. Environmental regulations applicable to mining in Japan

29. A relatively small indigenous mining capacity has forced Japan to invest in mining projects abroad in order to secure mineral supplies. It has developed a very strong smelting and refining industry at home and has invested increasingly in environmentally and economically efficient mining and smelting technologies for use at home and abroad (Warhurst, 1993). Initial environmental regulations aimed at the Japanese smelting industry tended to require the modernization of smelters and their being equipped with emission control technologies. These add-on controls were required to disperse waste gases through high stacks, recover modest amounts of sulphuric acid and remove dust through electrostatic precipitation. All new smelters required similar controls. Later, all existing and new Japanese smelters were required to install double-contact acid plants and/or sulphur dioxide scrubbing plants, fugitive gas collecting systems and waste-water treatment systems. In addition, individual firms were encouraged to develop innovative smelting technologies that improved environmental and productive performance. It was during this period that the state-of-the-art Mitsubishi smelting process was developed (Warhurst, 1993). Japanese air control requirements have become increasingly stringent - in line with those developed in the United States. However, since Japan does not mine its own minerals, it faces the unique challenge of confronting a wide variety of conditions and government regulations in the countries in which its mining and smelting industries operate. The response of Japanese mining and smelting firms has therefore been to set levels of a technological excellence that, in not only meeting but often exceeding government requirements elsewhere, often establishes best environmental practice in mining and smelting.

G. Environmental regulations applicable to the mining industry in Brazil

30. In Brazil, the central Government shares jurisdictional responsibility for the environment with the States and municipalities. The central Government legislates on various aspects of mineral resources related to development, but authority for legislating on environmental issues associated with mining is largely decentralized. There is no comprehensive set of rules regulating the mining sector in Brazil. Mining policy is largely set out in the Constitution which includes procedural guidelines regarding the granting of mining permits and various statutory laws (Andrade, 1993). The first initiative to institutionalize authority over the environment at the federal level was the creation of the Special Environment Secretariat in 1973. After its formation, a disparate set of rules and regulations were developed in an effort to control industrial pollution. Table 5 outlines the environmental regulations applicable to mining and metal processing in Brazil.

Table 5. Environmental policy and legislation applicable to mining in Brazil

Type	Regulations and policy
Command-and-control standards	National Environmental Policy (1981) and the 1988 Constitution require that environmental issues should be analysed by taking social, economic and institutional aspects into account simultaneously. Allowed for the development of ad hoc federal environmental rules applicable to mining. Most command-and-control environmental standards and pollution controls set at the state or municipal level
Permitting and environmental impact assessment legislation (or process)	Prior to establishment of mining operations, miners or mining firms must obtain environmental permission from an appropriate state environmental agency or from the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) Any area subject to environmental conservation measures (defined in specific regulations) requires special permission from the environmental agency that administers it prior to mining activity Use of water for processing of extracted minerals must also be approved by the Federal Department of Mineral Production (DNPM) and by an appropriate environmental body. Application for such permission must include a technical description of the process and how the water will be used Environmental impact assessment and report required before application to mine can be granted. Some States and territories require a public hearing on the environmental effects of new mining projects as part of their Constitutional legislation Appropriate state environmental body or IBAMA will issue, in turn, three types of permit: a prior licence, an installation licence and an operating licence. The installation licence requires the submission of a Plan for Recovering the Degraded Area (PRAD) under a specific provision of the 1988 federal Constitution

Type	Regulations and policy
	Garimpo (small-scale mining site) permit: prospective applications must be accompanied by an environmental licence. The holder of a garimpeiro permit (prospecting permit), mining concession, mine licence or manifest can be held responsible for damage caused to the environment
Economic incentives legislation	Mining operations that do not adhere to agreed environmental conditions in mining permits, or avoid applicable state or federal environmental regulations, can be penalized. Penalties include fines, loss of tax concessions or other incentives granted by public authority, loss of finance from official credit institutions and temporary or permanent licence suspension

H. Evolution of environmental regulations applicable to mining in Chile

31. The Chilean Law 3133, promulgated in 1916, represents one of the world's first attempts to apply environmental controls in the mining industry. It stipulated that unneutralized wastes from industrial sources should not be dumped in aqueducts, artificial or natural riverbeds, lakes, lagoons, or other water deposits. Permit requests for the development of new industrial plants and mining operations were required to list the characteristics of the wastes whose production was intended, their expected yearly discharge levels, and the methods by which they would be treated. The Ministry of Health administered the law and approved industrial permit applications. Law 3133 also noted that natural or artificial riverbeds containing drinking or irrigation water were not to be used for mine tailings deposit. As a pioneering attempt to control mine waste, Law 3133 laid a foundation for much of Chile's subsequent environmental law, particularly the Sanitary Code of 1968. 6/ Table 6 provides a summary of the environmental regulations applicable to mining and metal processing in Chile.

Table 6. Environmental regulations applicable to mining in Chile

Type	Description
General commitment to environmental protection	1980 Constitution of Chile's military Government, article 19 (amendment 8), declared that every citizen had the right to live in a contamination-free environment
Command-and-control legislation	Law 3133 (1916) stated that unneutralized wastes from industrial sources should not be dumped in water deposits
	Water Code of 1981: environmental controls for mine tailings
	Decree Law 3557 (1980/81) established water protection norms. Article 11 required mining operations to adopt technical measures to prevent contamination of agricultural land. Authorized President to temporarily or permanently shut down mining operations that threatened the health of populations, agricultural crops or livestock
	Decree 4 (Ministry of Agriculture) required the control of sulphur dioxide emissions in the area surrounding the Disputada de Las Condes Mining Company's Chagres smelter. June 1991 update (Ministerial Decree 28) established allowable levels of sulphur dioxide emissions. Article 3 of the updated Decree stated that the Disputada de Las Condes Mining Company must install, operate and maintain air quality systems that allowed detection and recording of sulphur dioxide levels that were within the permissible limits
	Supreme Decree 185 (1990) set up a complete and effective series of regulations to control atmospheric levels of sulphur dioxide, particulates and arsenic from metal smelters
Permit-based legislation	Law 3133 (1916): permit requests (Ministry of Health) for development of new industrial plants and mining operations were required to list characteristics of wastes, expected yearly discharge levels, and methods for treatment

Type	Description
	Sanitary Code (1968) Article 71 required the National Health Service to approve projects that deposited industrial wastes in the environment Article 72 empowered the Health Service to penalize violators of environmental conditions attached to industrial approval permits. Health Service's approval required for any industrial or mining project that takes place in areas where the natural flow or quality of water can be adversely affected

I. Evolution of environmental regulations applicable to mining in China

32. Environmental protection has received a heightened degree of government attention in China since the First National Environmental Protection Conference was held in Beijing in August 1973 (Gao, Wenmin and Xinhai, 1993). The Environmental Protection Leading Group was established under the State Council in 1974, and various national environmental standards were developed specifying norms for environmental quality and pollutant emissions. Since 1978, more significant progress in the area of environmental protection has been made. The Constitution of the People's Republic of China, adopted on 5 March 1978, states specifically that the State protects environment and natural resources against pollution and other public nuisances (Gao, Zhiyou and Wenmin, 1992). In September 1979, the Environmental Protection Law of the People's Republic of China was promulgated. Implementation of this Act marked the beginning of legislative environmental management in China. Table 7 outlines the environmental regulations applicable to mining in China.

Table 7. Environmental policy and legislation applicable to mining in China

Type	Regulations and policy
Command-and-control standards	Environmental Protection Law (1979) Marine Protection Act (1982) Water Pollution Prevention Act (1984) Atmosphere Pollution Prevention Act (1988) Supplemental administrative acts and rules applicable to the mining industry: implementing Rules for Water Pollution Prevention Act, the Provisional Measures for Collecting Pollutant Discard Charges, the Atmospheric Quality Standard, the Sea-Water Quality Standard and the Implementation Rules for the Atmosphere Pollution Prevention Act A large number of regional and local regulations have also been enacted by the provinces, municipalities and autonomous regions to control specific environmental problems associated with mining Land Reclamation Regulations (1988) set standards for reclaimed land
Liability legislation	Land Reclamation Regulations (1988) establish liability for reclaiming mined land, or impose penalties
Economic incentives legislation	Environmental Protection Law and other relevant regulations have been enacted, using economic incentives rather than the old style of propagandist slogans and education Mining enterprises generally benefit from reclamation work undertaken by receiving favourable taxation status and special credit
Permitting and environmental impact assessment legislation (or process)	Environmental Protection Law requires that environmental impact assessments be carried out prior to construction of new mining operations Also, pollution disposal facilities must be designed, built and made operational at the same time as the rest of a mining or smelting operation

J. Environmental regulations applicable to the mining industry in Ghana

33. In spite of the existence of an Environmental Protection Council (EPC), the mining industry in Ghana (until recently) has been subject to few environmental regulations. EPC has suffered from lack of funding and skilled personnel, and has had little implementation power. However, the World Bank's involvement in several Ghanaian mineral development projects has brought a new level of "green consciousness" to its mining industry. In 1988, EPC was asked by the Government to prepare an environmental action plan for making Ghana's economic development programmes more environmentally sustainable. Six committees were formed to develop a National Environmental Policy, one of which was the Mining and Hazardous Chemical Committee. In 1988, the Committee held a seminar that identified a serious lack of environmental education within domestic mining firms. An environmental regulatory framework has recently been developed for the mining industry and includes provisions for all new mining projects to undergo environmental impact assessment. Table 8 summarizes environmental regulation applicable to the mining industry in Ghana.

Table 8. Environmental regulations and guidelines applicable to mining in Ghana

Type	Guidelines	Regulations
Command-and-control standards	Minerals and Mining Law 1986: states that environmental protection in Ghana should be guided by a preventative approach Ghana Environmental Resource Management Project (1993): guidelines for exploration, mining, mineral processing and decommissioning	Minerals and Mining Law 1986: empowers the Minister to make regulations for conservation and development of mines and minerals. It is under this provision that environmental regulations are being made Local-level by-laws applicable to mining operations could be enacted in the future through District Planning Authorities
Liability legislation		Section 80 (1) (f) of the Minerals and Mining Law makes pollution of the environment an offence; section 81 (10) (a) makes directors and other officers of mining firms having knowledge of wilful pollution liable for the environmental offences of their firm. Penalties specified in Section 82 include fines and/or imprisonment for periods of up to two years

Type	Guidelines	Regulations
Permitting and environmental impact assessment legislation (or process)	Ghana Environmental Resource Management Project (1993): guidelines for preparation of environmental impact assessment statements for new mining projects and preparation of environmental action plans for existing mining sites	Clauses 4 and 5 (a) of the Prospecting Licence and Mining Lease require firms to conduct all their operations with due diligence, efficiency and economy consistent with good mining industry practice, using appropriate modern effective equipment and methods, paying particular regard to environmental protection National Environmental Policy stipulates that all new mines are required to have environmental impact assessments (EIAs) before licensing. Requires that all existing mines develop environmental action plans The Chief Inspector of Mines is empowered, under the terms of mining lease law, to require appropriate measures for compliance with environmental measures as well as to recover costs for such action from the company. Should these requirements not be met and wilful non-performance persist, the mining lease can be terminated

K. Influence of international environmental issues and agreements

34. Acid rain is the key transboundary problem associated with mining and non-ferrous metals production, although groundwater and surface-water pollution can cause regional problems, for example, mercury contamination from gold-mining in the Amazon. The political challenge in the European Community and North America of dealing with acid rain originating from neighbouring-country mining smelters is a key issue. The European Community now relies on the use of Directives that are applicable to all member States to achieve political aims with respect to acid rain. Despite this, not all member States have been equally willing to implement the changes required to reduce acid rain. A much more publicized case has been that of the controversy that existed between Canada and the United States over acid rain. Much of the 1980s was spent negotiating an international agreement between these two countries to achieve source reductions of sulphur dioxide. The result of these negotiations was the Canada/United States Agreement on Air Quality, signed in March 1991. As a result, the 1990 Amendments to the United States Clean Air Act directed

considerable attention to further control of sulphur dioxide and toxic emissions from mineral smelting operations. The United States Congress introduced a plan, under the authority of the Clean Air Act (1990 Amendments), to reduce sulphur dioxide emissions from 1980 levels by 10 million tons. A national cap of 8.9 million tons of sulphur dioxide per year is required by the year 2000. The Agreement also committed the Government of Canada to overseeing the reduction of sulphur dioxide emissions by 40 per cent of 1980 levels by 1994. 7/ All mining operations having smelters in the seven easternmost provinces of Canada are required, under the Canada/United States Agreement on Air Quality, to reduce their sulphur dioxide emissions to the agreed level. The provincial Governments, by entering into agreements with the federal Government, have been largely responsible for enforcing the required reductions at smelters within provincial boundaries.

35. It is highly probable that international environmental issues and agreements will have a more significant impact on the world mining industry. The current world-wide interest in making environmental issues relevant to trade in world commodities will likely require that all nations produce metals and minerals in an environmentally sound manner in order to avoid restrictive trade barriers in some form. Such agreements may have positive and negative environmental consequences for the world mining industry. The Basel Convention on the control of Transboundary Movements of Hazardous Wastes and their Disposal, which attempts to regulate the trade of hazardous substances, is a good example. Many metals that could be recycled more effectively by countries that wish to do so are currently not transported across national boundaries because of restrictions applied by the Basel Convention. However, the Basel Convention also prevents the transport of mining slag from developed countries to the underdeveloped ones that cannot treat the waste (but may wish to earn foreign exchange through payment for its disposal). On a positive note, environmental codes or agreements applicable to key mining industry processes, enforced by an international trade regulatory body, could push world best practice in environmental management to new levels, although they might have negative competitive implications for certain developing country firms that are constrained by obsolete technology and scarce resources.

L. Problems of conflicting and changing environmental regulations

36. By 1980, economists, business leaders and politicians had confirmed that environmental regulation was costly, in terms of both the administrative costs borne by taxpayers and the indirect costs placed on the economy (United States, Environmental Protection Agency, 1979). Since environmental regulations had not been designed initially with cost-effectiveness and efficiency in mind, it is hardly surprising that they failed to meet such criteria. Hence, many of the goals of environmental regulation were not achieved in the 1970s. Environmental problems were much more difficult (and expensive) to solve than either the public or politicians had imagined. As a result, politicians in the United States now require regulatory agencies to provide information about what areas they are thinking of regulating, to publish preliminary regulations and to hold hearings before deciding final rules or guidelines (Gruenspecht and Lave, 1989). In the United States, the public may challenge regulatory proposals during the

hearing process or through the courts. The courts have reacted to this challenge by examining not only whether the Environmental Protection Agency has followed due process and statutory authority, but also whether their own actions seem reasonable. The American President (through executive order) has also required EPA to carry out cost-benefit analysis on potential regulatory options and to explain why certain options are chosen over the alternatives. Such trends are also present, albeit to a lesser degree, in Canada. These processes are cumbersome, requiring large amounts of professional work and analysis as well as time to establish final rules. The result of all this deliberation is usually weak, contradictory regulatory goals.

37. Rothwell (1981) found little evidence to suggest that regulatory agencies were adequately staffed to assess the impact of their activities (or their planned activities) on industrial innovation. He also noted widespread lack of clarity in regulatory language and in the official strategies for those activities' implementation. The allowing of considerable administrative discretion in the interpretation of regulatory terminology such as "best available technology" or "best practicable technology" was also considered an administrative weakness. Vague language in regulations often left room for authoritative differences in opinion (and for legal challenge). Subjective use of the language of regulations has therefore been noted as a major cause of uncertainty in industry, which in turn has had a negative impact on technological innovation. Regulatory frameworks that are broad in scope (made to apply to entire industrial sectors with little or no flexibility for regional, geographical or environmental deviations) are thought to indirectly repress industrial innovation. Imprecision in environmental regulatory requirements may be caused by a number of factors including technical uncertainties as well as by the extent to which interest groups or the public can provide further relevant information to government and/or apply pressure for accommodation through formal or informal means, according to Ashford, Heaton and Priest (1979). These authors have also argued, however, that the uncertainty associated with environmental regulation can be both necessary and beneficial for stimulating technological innovation. In their opinion, regulatory uncertainty is an inevitable consequence of accommodating the administrative flexibility that allows environmental regulations to be improved. While recognizing that levels of uncertainty can become so great that inaction on the part of industry results, they also maintain that too much certainty about final regulatory standards is not likely to lead to the development of technology fulfilling more than the minimum requirements.

38. Environmental regulations are also often contradicted by economic and industrial policies. For example, several countries with tropical forests have recently introduced policies aimed at the conservation of those forests. At the same time, countries such as Brazil, Ecuador and Colombia have parallel economic policies to promote industrial investment, especially by foreign firms, in these remote areas. In one such case, the Government of Ecuador authorized the mining investment of Rio Tinto-Zinc Corporation (RTZ) in one of its national parks; this resulted in the firm's withdrawing to avoid controversy over the issue. Similarly in Brazil, forest conservation policies were in place (this being in part conditional upon EC and World Bank loans), yet the Carajas smelters continued to be fuelled by large amounts of charcoal from the neighbouring forests. In essence, the problem with the command-and-control mode of

environmental policy is that it deals with the regulation of industry and not with its promotion. However, if production efficiency and innovative capability, ahead of regulatory regime, are the major determinant of environmental performance in firms, then environmental policy needs to address the issue of the barriers and incentives to innovation. Pollution prevention regulation goes some way towards recognizing the problem, but it does not incorporate comprehensive policy mechanisms that can deal with both the causes of environmental mismanagement and the need to foster production efficiency and innovativeness. This is the subject of sections III and IV.

III. CHANGING ENVIRONMENTAL MANAGEMENT PRACTICES IN THE MINING INDUSTRY

39. The fundamentally different nature of technical change and therefore of environmental costs involved in applying pollution prevention to metal mining operations can be usefully illustrated by employing the concept of "corporate environmental trajectories". Such trajectories describe the evolutionary development of a firm's competitiveness and environmental performance in response both to changing market conditions and to regulatory requirements. Governments, and indeed corporate strategists, need such policy tools to enable them to predict the environmental practices and competitive behaviour of firms under different market conditions and regulatory regimes, and to identify the warning signs of declining competitiveness, impending mine closure, and consequential environmental effects. For example, mine closure can be prompted by combined regulatory and market pressures, in advance of expected ore depletion. However, in many countries a bankrupt firm is no longer responsible for its clean-up problem and the burden frequently falls on the State, which has neither the resources nor the skills to deal with the scale and complexity of the problem. (See Warhurst (1992) regarding the case of Carnon Consolidated, Limited, in the United Kingdom, and numerous articles about the Summitville mine Superfund site in Colorado (United States).)

A. Technical change and corporate environmental trajectories

40. Enterprise responses to environmental pressures have been characteristically slow, and reflect predominantly the regulatory regimes and the climate of pubic opinion in the enterprise home country. Response also depends on the nature of the operations of the enterprise in terms of the following: first, the mineral involved; second, the level of integration of mining and processing activities; third, the stage in the investment and operations cycle that its mineral projects have reached; fourth, the internal economic and technological dynamism of the firm (in other words, whether it has the financial, technical and managerial capabilities to be an innovator).

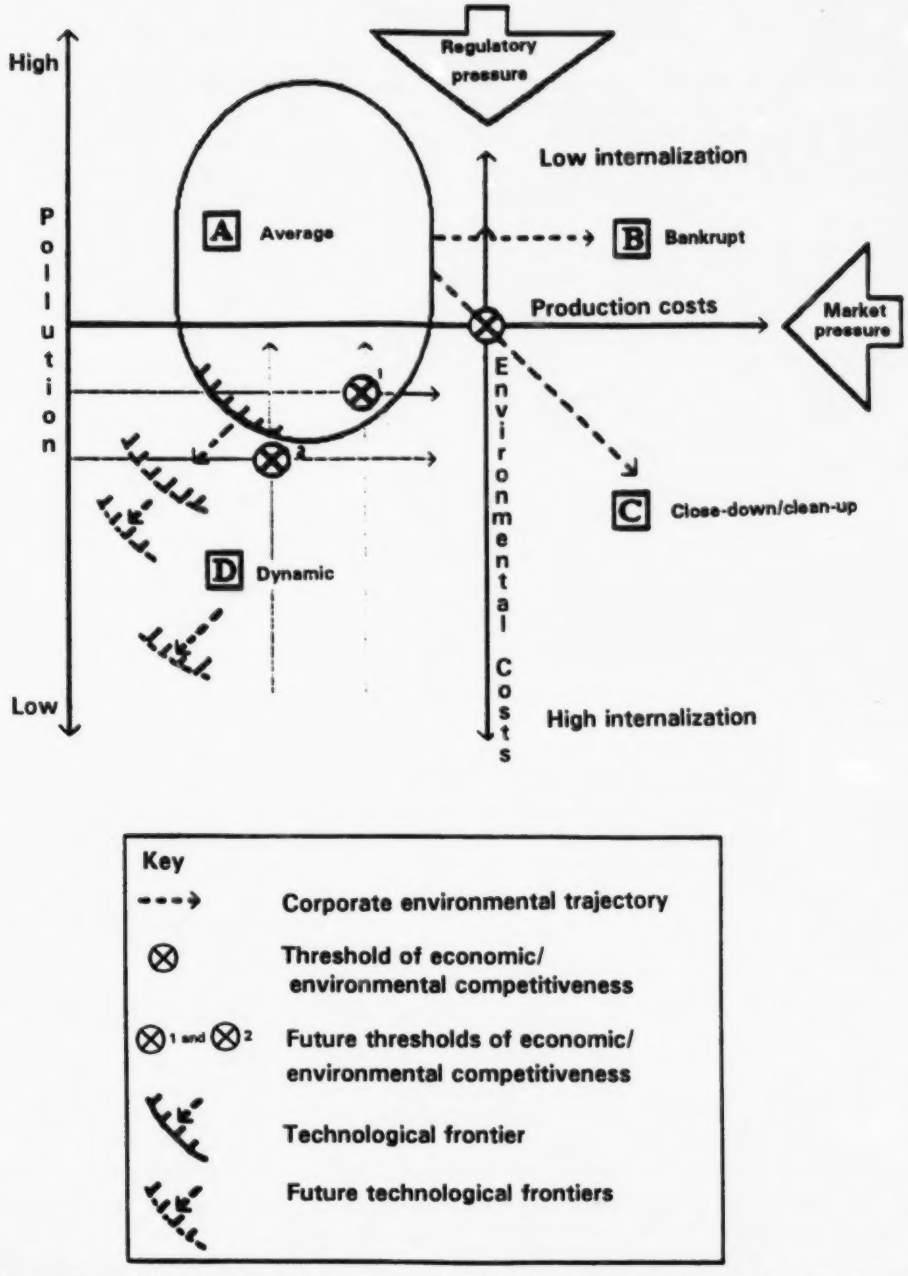
41. After a period of using rather "static" technology, the mining and mineral processing industry is currently going through a phase of technical change as dynamic firms develop new smelting and leaching technologies to escape economic as well as environmental constraints. Rapidly evolving environmental regulatory frameworks in the industrialized countries and the prospects of their application, reinforced by credit conditionality in the developing countries, are stimulating this trend. Changing technological and environmental behaviour in this context is evident particularly in the large North American and Australian mining firms as described above, but is also becoming apparent in developing country-based firms operating in, for example, Chile, Brazil and Ghana. However, it seems to be the new operators and dynamic private firms that are changing their environmental behaviour, while both State-owned enterprises and small-scale mining groups in developing countries, with some exceptions, continue to face constraints regarding their capacity to change environmentally damaging practices.

42. It is inevitable that only those firms that are dynamic and have new project development plans are in a position to invest in the research and development required to develop more environmentally sound alternatives, or to raise the capital to acquire those alternatives from technology suppliers. Indeed, after a long period of conservative and incremental technical change, alternative process routes for mineral production are being developed and these are emerging as economically more efficient as well as environmentally less hazardous. Furthermore, firms are beginning to sell their innovative technologies (since they prefer to commercialize them so as to recoup their research and development costs) rather than their obsolete ones (and thereby risk shareholders' displeasure or retrospective penalties as environmental regulations are increasingly enforced in developing countries). Some mining firms have even pushed the capacity of their technology to comply with regulations beyond existing bounds. As a consequence they are seeking to increase regulation, particularly on a worldwide scale, because in meeting stricter standards, they can use their new environmentally sound technologies to their competitive advantage.

43. The environmental trajectories that different mining firms might follow in response to environmental and market conditions are categorized in figure II. This diagram could be a planning tool for both firms and Governments. It can help to evaluate the environmental and economic implications of applying different policies. The average mining firm demonstrates competitiveness (as represented by the area to the left of the threshold of economic competitiveness, X), although to a greater or lesser extent such firms produce environmental pollution and, also to a greater or lesser extent, have internalized, in response to the regulatory regime they are working within, the cost of the environmental degradation associated with their metal production. (The threshold of "environmental competitiveness" for a given regulatory context is also representable by X and firm operations exhibiting compliance with such regulation have environmental trajectories that, as depicted in figure II, may be located in the quadrants below the horizontal axis.) However, owing to market pressures - mainly a real decline in metal prices - combined with the economic inefficiencies of the firms, some of them go bankrupt (this is represented by a trajectory towards quadrant B). They will leave a legacy of environmental pollution behind, and as in the case for example of Bolivia's State mining firm and of Carnon (in the United Kingdom), the burden of clean-up will fall on the State and society. Other firms will respond by innovating (represented in figure II by the move into quadrant D), and building into the new generation of technology both improved economic and environmental efficiencies (protecting themselves in the meantime from having to undertake relatively more costly add-on, incremental technical change and rehabilitation at later stages in their operation). Indeed, freed from the incumbent costs of retrofitting sunken investments, greenfield plants in particular can often display new levels of dynamism, since the latest "best-practice" technology incorporates both improved economic and environmental efficiencies.

44. Nonetheless, there exists a growing group of firms that, if obliged to "add-on" environmental controls in line with new regulations, would have to close down, since the cost of the controls and clean-up required would render their operations uneconomic. In figure II, the environmental trajectories of those firms is towards quadrant C. Currently, such examples are few, and it is

Figure II. Corporate environmental trajectories



Source: Dr. Alyson Warhurst, Science Policy Research Unit, University of Sussex, United Kingdom, 1993.

difficult to differentiate between purely environmental factors and the range of other reasons why a firm's cost curve starts increasing. However, as figure II shows, the size of this group would be expected to grow, since with combined market and regulatory pressures' lowering the threshold of economic and environmental competitiveness, the average firm will survive in the new regime only if it innovates. Therefore, even the previously dynamic firms will need to keep their environmental trajectories moving ahead of the encroaching thresholds of economic/environmental competitiveness (X^1 and X^2).

45. Those trajectories imply a serious constraint on the regulatory process for two reasons, which distinguish mining firms from their manufacturing counterparts. First, an implied close-down due to regulatory burden does not signal the end of environmental degradation. Pollution in metals production, in so far as it is not all of an end-of-pipe nature, does not stop when production ends. Rather, it heralds a new phase of environmental management: decommissioning, clean-up and rehabilitation - all of which impose significant costs. Second, only in very few countries are operators liable, once operations have closed, for the clean-up of their "sins of the past". The United States with its Superfund liability laws, is an exception. Therefore, pushing forward the technological frontier and moving the threshold of economic and environmental competitiveness may increase the overall extent of environmental degradation (particularly that without liability). The environmental imperative's policy challenge, which the pollution prevention proponents must face, is therefore how to keep firms sufficiently dynamic to be able to reduce their pollution at source, clean up profitably pollution that "escapes" and, in the meantime, generate increasing amounts of economic wealth. The policy challenge is therefore environmental innovation. This means combining the regulation and promotion of industrial activity into an integrated policy.

B. Environmental innovators

46. Although some mining firms have resisted the application of environmental regulation to their existing operations, a growing number of dynamic innovative firms are making new investments in environmental management. In part, this is because those firms see an evolution towards stricter environmental regulation, and it is also to their competitive advantage to be pushing environmental and technological frontiers forward. Free of the encumbrance of sunken investments in pollutant-producing obsolete technology, or with significant resources for research and development and technology acquisition, they have chosen either to develop cleaner process alternatives or to select new improved technologies from mining equipment suppliers (who are themselves busy innovating). Increasingly, new investment projects are incorporating both improved economic and environmental efficiencies into new production processes, through not just the appearance of new plants or equipment, but also the development of improved management and organizational practices.

47. Examples of innovation to reduce smelter emissions, improve the efficiency of metals extraction and improve waste management have emerged in several case-studies (Warhurst, 1993). For instance, more than 12 per cent of Inco's capital spending during the last 10 years has been related to environmental concerns (Coppel, 1992). Modernization plans include replacement of its reverberatory

furnaces with a new innovative oxygen flash smelter, a new sulphuric acid recovery plant and an additional oxygen plant. By incorporating two of the flash smelters the firm reduced sulphur dioxide emissions by over 100,000 tons per year in 1992, and by 1994 planned to achieve a government-set target level of 175,000 tons per year. Other environmental benefits have included a cleaner, safer work environment (Mining Journal, 23 February 1990). Inco is now one of the world's lowest-cost nickel producers. Furthermore, like other dynamic firms that are responding to environmental regulation through innovation, Inco is seeking to recoup research and development costs through an aggressive effort to license its technology with firms in other copper-processing and nickel-processing countries. Homestake's McLaughlin gold-mine in California is a good example of a new mine and processing facility that has been designed, constructed and operated from the outset within the bounds of the world's strictest environmental regime. (The gold-mine of Kennecott, at Barney's Canyon in Utah, is another example (see Warhurst, 1992c).) Environmental efficiency is built into every aspect of the gold-mining process. Innovative process design criteria, fail-safe tailings and waste disposal systems and extensive ongoing mine rehabilitation and environmental monitoring systems characterize Homestake's McLaughlin site. The mining operation, therefore, combines a myriad of innovative technologies to define "best practice" in environmental management. The most interesting conclusion drawn by the author from site visits and discussions with the firm's environmental officers is that most of these environmental management initiatives have not resulted in any substantial extra cost; indeed many have improved the efficiency of the mine, and this has positively affected the economics of the overall operation.

48. In conclusion, these few examples suggest that dynamic firms are not closing down, reinvesting elsewhere or exporting pollution to less restrictive regulatory regimes in developing countries. Rather they are adapting to environmental regulatory pressures by innovating, improving and commercializing their environmental technology and management practices at home and abroad. This evidence challenges the "pollution haven" hypothesis.

C. Cleaning up "sins of the past"

49. Notwithstanding the positive evidence concerning environmental innovation, it is undeniable that those firms with long mining histories and extensive sunken investments in conventional mining and smelting facilities face the greatest technical, and therefore economic, challenges, in cleaning-up their past operations, and in accounting for their sins of the past. For example, some firms in the central and south-western United States have found that past lead and copper mining operations, which resulted in the construction of large-scale mineral dumps, are now creating such serious acid mine drainage and toxic seepage as to have obliged the Government to place those dumps on its "Superfund list", requiring multimillion dollar sums to be spent on their clean-up.

50. It is usually those very mining firms that need to control their sins of the past that protest most about regulation, particularly retrospective regulations, and suggest that such restrictions and controls threaten their existence. Significantly many developing country-based firms with older

operations would probably also fall into this category. There exist many old and abandoned mines presenting these types of environmental degradation problems. Searching out the many foreign investors that have long since returned home, or indeed the bankrupt local miners concerned, makes the task of determining liability and enforcing clean-up a daunting one in the developing country context. Even where State ownership exists, the resources and skills required to assure that environmental liability are rarely processed, although such ownership might be shown to provide economic opportunities to local firms to participate in clean-up.

IV. CONCLUSIONS: POLICY TO PROMOTE ENVIRONMENTAL INNOVATION

51. There are two types of policy mechanisms that can be used to promote environmental innovation in industry, and therefore to encourage a pollution prevention approach. The first set includes expenditure programmes to support research and development, environmental engineering, clean technology development and training in environmental management. The second set comprises incentives to stimulate and reward firms for environmental innovation and technology diffusion.

A. Supporting clean technology development

52. Technology policy mechanisms to assist the funding of clean technology development include the targeting of research and development in selected areas of pollution prevention. These would include examples (from Canada) of research and development programmes, inter alia, in acid mine drainage, and biotechnology to clean up effluents. Such mechanisms would also include co-funding of research and development projects involving inter-industry and industry-university/industry-research institution collaboration. Such programmes could be supported through easily accessible centrally compiled information dissemination programmes about moving technological and regulatory frontiers. A crucial point with regard to targeting support for research and development relates to how the innovation process within industry works. Too often in policy documents, innovation is conceptualized as something that builds on research and development undertaken in government or university laboratories and is then magically applied by industry throughout its operations. Such thinking is reflected, to a certain degree, in EPA documents regarding its aims in the area of technological innovation. 8/ Evidence of how innovation takes place, however, suggests that in most cases it is industry-driven, with firms drawing for the additional knowledge, expertise and technology that they require on research institutions and other firms, so as to complement their in-house research and development and engineering efforts (Rothwell, 1992; Warhurst, 1993). An important element of technology policy with respect to promoting source reduction innovation should be the inhibition of the possible tendency of firms to divert resources from conventional business research and development towards compliance-related research and development. To improve the efficiency of the production process, there should be a focusing of research and development effort on process innovation and an integration of pollution prevention at source into an overall effort. Both aims should be complementary. 9/

53. Targeting firms as innovators of pollution prevention technology requires a number of important changes in policy-related thinking. A multimedia approach is needed, since pollution prevention requires changes in process technology - not the addition of "off-the-shelf" end-of-pipe controls, which tend to shift pollution from one medium to another. Such charges in process technology require a range of engineering skills harnessed to deal with the reduction or the elimination of the pollutant at source (independently of where it may ultimately be discarded). New technology must be designed to deal not only with water and air quality and waste, but also with workers' health and consumer products' safety. This means that training for research and development engineers in industry should be a critical element of pollution prevention policy. Management training is also important, as is the introducing of engineers and miners to new work methods. There is also a clear relationship between good housekeeping at the plant site and environmental practices. Therefore, technology hardware is only one part of the equation. Of equal importance is the need for organizational change in firms. Much can be learned from the manufacturing sector regarding the development and success of "lean production" and related Japanese work methods such as "just in time" inventory control, waste reduction throughout the system, total quality management and statistical process control. The implications of applying lean production principles to the mining industry, or of developing radical process innovations with similar effects, would be remarkable. Markedly lower investment and production costs combined with the halving of mine development time and mine life could have significant implications for the competitive structure of the industry as well as the reducing of associated negative environmental and social effects. Few mining firms have taken these ideas on board. Those that have considered alternative organizational methods include CRA (Australia), Homestake's McLaughlin Mine (California) and Scuddles Mine of the Poseidon Group in Australia. 10/

B. Firm incentives for environmental innovations

54. Changes may be necessary in taxation policy in order to promote environmental innovation. According to Ashford (1991), the United States currently gives taxation incentives in the form of accelerated depreciation for pollution control equipment, thus supporting end-of-pipe pollution control. However, investments in new production technology are not similarly treated, so that dollar for dollar a firm would be better off buying from an environmental technology vendor than developing process changes. Direct taxation concessions and incentives can be applied to investment in pollution prevention technological or organizational change; research and development; engineering projects and training in specific areas of environmental management; posting of bonds upfront for future pollution prevention, or reclamation on closure. Punitive taxation on reagent use or energy use requires the careful consideration of its effects on both competitiveness and firm behaviour since different deposits, due to geology and chemistry, pose quite different implications for energy and reagent consumption patterns. Taxation in this context of ongoing operations may be perceived by operators as prejudicial and unfair. This suggests that flexible taxation provisions that allow and encourage innovative responses by industry are needed to complement strict standards and regulatory goals Regulators must possess an intimate knowledge

of the types of gains made by firms from technological change, in order first to determine how best to promote technological innovation, and second to respond by adapting or "ratcheting" regulation accordingly (Milliman and Prince, 1989). Innovative firms should be able to use environmental regulations to their competitive advantage. Benefits to such firms arise from the tightening of "technology forcing" regulation so that other firms are stimulated either to invest in new technology or to license (or purchase) the innovator's technology (thus enabling the innovator to recoup some of the costs of its initial investment in research and development). Regulatory authorities need to be seen to respond in this way. Moreover the rate of technological advance in pollution control is probably, at least for the informed regulator, the most useful criterion by which to judge the effect of environmental policies. (Such a view is reinforced by a growing number of researchers including Milliman and Prince (1989); Kneese and Schultze (1978); and Orr (1976).) This represents a formidable challenge for developing countries' regulatory agencies. Training for regulators, including industrial experience and salary packages commensurate with those of their corporate counterparts, will therefore be an important part of the pollution prevention approach. The pushing forward of the technological frontier in this way has the effect of pulling down the thresholds of economic and environmental competitiveness deeper into quadrant D of figure II. Consequently, the market conditions governing metals production also change to the innovator's advantage. An important corollary of the matter of incentives to innovate involves the regulatory response to innovation through "reward". Usually this is discussed in terms of the awarding of prizes for sound environmental management such as EPA's recent idea of an Environmental Leadership programme to reward American innovators. However, the reward side of the equation needs to be rendered more sophisticated by analysing how commercial gains to technological innovation and technology diffusion can be realized and expanded.

55. Another important component of environmental policy to support innovation concerns market incentives. Milliman and Prince (1989) found that, on a relative basis, direct controls - which are the most common regulatory tool - provided the lowest incentives to promote technological innovation in firms. Free permits and emission subsidies were also found to provide low incentives, while emission taxes and auctioned permits provided the highest incentives by virtue of rewarding the innovator with positive gains exceeding those related to the firm's own application of the technology through the accrual of benefits deriving from its diffusion to other firms. 11/ This is not surprising since for polluters with high costs of abatement it will be cheaper to buy permits than to reduce their emissions; polluters with low abatement costs will sell permits accordingly. Firms therefore have a constant incentive to cut emissions, since this allows them to sell permits. As such, tradable permits have the advantage over pollution charges in that they can guarantee the achievement of particular pollution targets, since the authorities control the number of available permits.

56. Finally on this issue, incentives need to be found to stimulate "auxiliary" firms to develop and commercialize innovative clean-up technologies including re-mining techniques. In developing countries, particularly, the market for such activities is vast, and donor agencies and development assistance grants could play a key role in stimulating such investment. 12/ In the United States,

especially, liability regulation will need to be reassessed to remove the current barriers to re-mining and to treating existing mining waste.

C. The diffusion of environmental innovation and technology transfer

57. Not only are technological and managerial capabilities required to innovate or to deal with new and emerging technologies, but they are also vital to an environmental management strategy using existing technology and owing to the need to resolve pervasive inefficiencies. Technology transfer and technology partnership through joint venture arrangements or strategic alliances constitute one way to build up technological and managerial capabilities to overcome these constraints. This is particularly true in the developing country context, although such strategic alliances are emerging in all the major mineral-producing countries. There is also a need to broaden the common concept of technology transfer to achieve the desired result of a real transfer of environmental management capability. Traditionally, technology transfer has meant a transfer of capital goods, engineering services and equipment designs - the physical items of the investment, accompanied by training in the skills and know-how for operating plant and equipment. As a consequence, the innovative capacity of recipients is undeveloped and they remain purchasers and operators of imported plant and equipment. This is the case especially in developing countries, as recipients become dependent upon their suppliers to make changes or improvements in successive vintages of technology. Contractual conditions may reinforce this situation. New forms of technology transfer in environmental management need to go further so as to embrace, first, the knowledge, expertise and experience required to manage technical change - of both an incremental and a radical nature - and, second, the development of human resources to implement organizational changes to improve overall production efficiency, energy efficiency and environmental management throughout the plant and facility, from mine development through production, to waste treatment and disposal.

58. In global industries such as mining, international firms play a major role in supplying significant amounts of managerial and engineering expertise through joint ventures and other collaborative arrangements. Usually such technology transfer is restricted to the immediate requirements of the specific investment project or item of equipment purchased. Flows of technology may even be structured to match regulatory requirements. Cumulative command-and-control regulation tends to lead to incremental, add-on, end-of-pipe, capital-intensive technical change, and therefore to successive rounds of technology importation (Warhurst, 1992c). Empirical research on other sectors demonstrates, however, that there exists considerable potential to increase those contributions without adversely affecting the supplier's strategic control over its "proprietary" technology (Bell, 1990; Warhurst, 1991a, 1991b; Auty and Warhurst, 1993).

59. There already exists a range of commercial channels through which mine operators can purchase capital goods, engineering services and design specifications; however, the market for knowledge and expertise, including training programmes, is less mature. It is the active development of this market that will "reward" innovators of pollution prevention technology. Bilateral and multilateral agencies, development banks and government

organizations can play a major role in improving this situation. Agenda 21, 13/ one of the main outputs of the United Nations Conference on Environment and Development, proposes two programmes of relevance (Skea, 1993), which should also lead to greater involvement by industry. The first programme encourages interfirm cooperation with Government support to transfer technologies that generate less waste and increase recycling. The second programme on "responsible entrepreneurship" encourages self-regulation, environmental research and development, worldwide corporate standards, and partnership schemes to improve access to clean technology. Moreover, Agenda 21 (chap. 34) recognizes that effective mechanisms for technology transfer require a substantial increase in the technological capabilities of recipient countries (Barnett, 1993). It is the capacity to effect technical change, not just the skill to operate an item of environmental control technology, that will ultimately determine the success with which recipient firms build up and sustain competence in environmental management, and the capabilities to implement environmental innovation. Broadening the concept of technology transfer to encompass these issues would also enable the policy makers in government and industry to assess more accurately barriers to the diffusion of clean technology.

D. Conclusions

60. This report has reviewed and evaluated different environmental regulatory modes applied to the world mining industry. It has emphasized the emerging regulatory principle of pollution prevention which aims to promote the competitive and environmentally sustainable development of industrial production. By virtue of the requirement to reduce pollution at source, pollution prevention requires a priori that change be made either to the technology or organization of the production process, or to both. This requires, to differing degrees, the development of new technological and managerial capabilities within the firm, technological alliances with equipment suppliers and collaboration with research and development organizations. This report has argued, however, that the successful implementation of pollution prevention will require regulatory approaches to be quite different from those in existence in the key countries reviewed.

61. In summary, pollution prevention targeted at different types of mining and mineral processing firms might better serve its objectives if it were underpinned by technology policy mechanisms and economic instruments aimed at:

(a) Stimulating and rewarding environmental innovation through, for example, research and development and technology investment tax breaks, and other taxation reforms, auctioned pollution permits, opening of new lines of credit, targeted research and development support and training programmes, mandatory pollution prevention and reclamation plans in project development, and posting of bonds for that purpose;

(b) Stimulating profitable innovation in that part of the pollution cycle involving waste management, including re-mining, reagent and metals recovery, and biotechnology applications for waste treatment. This would also include the removal of legislative barriers inhibiting re-mining and waste treatment;

(c) Facilitating and rewarding the commercialization and diffusion of pollution prevention technology and work practices across the boundaries of firms and nations, using mechanisms such as credit conditionality and new approaches to technology transfer. These would include interfirm collaboration to develop the technological and managerial capabilities to innovate, in-depth training beyond the requirements of operating skills, and information dissemination programmes.

62. This analysis recognizes that innovation can change the broader context within which metals production and subsequent pollution takes place, and that the widespread diffusion of innovation can reward and stimulate innovators as well as contribute to the furthering of best practice in environmental management as a route towards sustainable development. The argument is that pollution prevention policy mechanisms would be more successful if they focused on the process of innovation, at any point in the life cycle of the mine, rather than penalized the extent of use of inputs or production of outputs. These vary too much between operations owing to the site-specificity of geology and geography. Penalties would differentially distort operations' cost-structures and would be an inefficient way to stimulate innovation in environmental management.

63. This report also makes a case for the training of regulators, as well as mine managers and engineers, since technological advance is an important indicator of the effectiveness of environmental regulation and the subsequent ratcheting of regulation could further enhance the competitive advantage of firms. It is suggested that regulators, as well as corporate analysts, might also be assisted in their strategies to achieve competitive environmental best practice by the definition of environmental trajectories in different economic and regulation contexts. These would evaluate the evolutionary development of a firm's competitiveness and environmental performance, in response both to changing market conditions and to regulatory requirements, and therefore its contribution to sustainable development goals.

64. The broadening of the range of regulatory goals, and the technology policy mechanisms and economic instruments that would need to be in place to support them would, as proposed here, in totality constitute a more integrated policy approach towards both regulation and promotion of industrial development as well as towards trade and technical assistance abroad. Pollution prevention at source and command-and-control regulation would play a key role in this policy, but would not always take priority in the competitive and environmentally sustainable development of minerals production in developing and industrialized countries. The new, more comprehensive and effective approach argued for in this report constitutes an environmental innovation policy.

Notes

1/ After the signing of the original Water and Air Pollution Control Acts, implementation and enforcement were inconsistent across States owing to the perceived economic disadvantages of environmental regulation.

2/ The decision to establish the Environmental Protection Agency (EPA) as an independent regulatory agency had a number of political implications. For example, the separate agency created a problem of coordination and achieving regulatory consistency and coherence. Other federal departments and agencies were in charge of fulfilling several other environmental objectives and missions. EPA had trouble coordinating its regulatory efforts with the missions and regulations of these other institutions.

3/ One author has gone as far as to describe the Canadian environmental regulatory system as a "contradictory web of interlocking responsibilities" in which different ministries at the same or different levels of government attempt to accomplish different missions and have overlapping responsibilities on a variety of issues. See O. Richardson, "Environmental policy-making and Ontario's mining industry", CRS Perspectives, vol. 45 (July/August 1993), pp. 2-9.

4/ The federal Government in Australia presently has no direct powers under the Constitution to legislate in the environmental area. However, in mid-1989, the Australian Prime Minister indicated that the federal Government would seek to have the federal Constitution amended to give the Commonwealth express powers over environmental matters. See Aston (1990).

5/ While legislation is uniform, monitoring and enforcement often differ significantly from State to State depending, inter alia, upon community attitudes, land-use pressures or conflicts, biophysical characteristics and population pressures. See Lootens and Kiernan (1990).

6/ The Sanitary Code of 1968 prohibited the discharge of mining wastes into rivers, lakes and other water sources used for drinking, irrigation or recreation, unless they received adequate purification prior to discharge.

7/ The Agreement is applicable only to the seven easternmost provinces: Newfoundland, Nova Scotia, Prince Edward Island, New Brunswick, Quebec, Ontario and Manitoba.

8/ There is no mention of the support of research and development and engineering in the firm; innovations are considered to originate in research institutions and universities and it is suggested that policy should focus on such support.

9/ Rothwell (1981) distinguishes between two types of innovation by firms subjected to environmental regulation. Commercial (offensive) innovation is typically conducted in the absence of environmental regulation. Compliance (defensive) innovation is conducted specifically for the purpose of complying with environmental standards. See also Isnor (1993).

10/ Scuddles has implemented an innovative multi-skilled approach to human resource development at its underground mine in Western Australia (Mining Magazine, January 1991).

11/ The arguments explaining these conclusions and the qualifications to be taken account of are long and complex and for brevity's sake are not repeated here. The reader is therefore referred to the original text of Milliman and Prince (1989).

12/ For example, over two thirds of the current mineral reserves of Bolivia are in dumps and tailings (Warhurst, 1992a). Furthermore, in many developing countries, such as Peru, there are many small-scale and medium-scale dynamic firms that supply a range of inputs to the mineral sector and could, with incentives, expand their activities to the environmental arena (Nuñez, 1993).

13/ Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 3-14 June 1992, vol. I, Resolution Adopted by the Conference (United Nations publication, Sales No. E.93.I.8 and corrigendum), resolution 1, annex II.

Bibliography

Acero, L. (1993). The case of bauxite, alumina and aluminium in Brazil. Mining and Environment Research Network, Working Paper Series (February).

Acquah, P. C. (1993). Recent trends in environmental management of the industrial mining sector in Ghana. Paper presented at the Third Annual Mining and Environment Research Network Workshop, Wiston House, Steyning, United Kingdom, 14-16 September 1993.

Acton, J. P., and others (1992). Superfund and Transaction Costs: The Experiences of Insurers and Very Large Industrial Firms. Santa Monica, California, Institute for Civil Justice, Rand Corporation.

Aitken, R. (1990). Personal communication, Inco, Ltd.

Andrade, T. (1991). Environmental issues of Brazilian tin production. Unpublished working paper, Mining and Environment Research Network, Science Policy Research Unit, University of Sussex, Falmer, Brighton, United Kingdom (May).

Ashford, N. A. (1985). Regulation as a stimulus for technological change. In Design and Innovation - Policy and Management, R. Langdon and R. Rothwell, eds. London: Frances Pinter.

_____ (1991). Legislative approaches for encouraging clean technology. Technology and Industrial Health, vol. 7, No. 516, pp. 335-345.

_____ and G. R. Heaton (1979). The effects of health and environmental regulation on technological change in the chemical industry. In Government Regulation and Chemical Innovation, C. T. Hill, ed. Washington, D.C.: American Chemical Society.

_____ and W. C. Priest (1979). Environmental health and safety regulation and technological innovation. In Technological Innovation for a Dynamic Economy, C. T. Hill and J. M. Utterback, eds. Oxford: Pergamon Press.

Ashford N. A., C. Ayers and R. F. Stone (1985). Using regulation to change the market for innovation. Harvard Environmental Law Review, vol. 9, pp. 419-466.

Ashford, N. A. and others (1979). Environmental/Safety Regulation and Technological Change in the U.S. Chemical Industry. Cambridge, Massachusetts: MIT Centre for Policy Alternatives.

Aston, R. L. (1990). Recent environmental laws affect mining. Mining Journal Environmental Supplement, vol. 315, No. 8,085, pp. 16-17.

Auty, R. and A. Warhurst (1993). Sustainable development in mineral exporting economies. Resources Policy (March).

Barbour, A. K. (1993). Environmental management systems in the extractive industries. Paper presented at the Third Annual Mining and Environment Research Network Workshop, Wiston House, Steyning, United Kingdom, 14-16 September 1993.

Barnett, A. (1993). Technical co-operation, technology transfer and environmentally sustainable development: a background paper for the Development Assistance Committee (DAC) Working Party on Development Assistance and the Environment. Paris: Organisation for Economic Cooperation and Development, March.

Barreto, M. L. (1991). Mining and environmental statutory laws in Brazil: a general overview. Unpublished working paper. Mining and Environment Research Network, Science Policy Research Unit, University of Sussex, Falmer, Brighton, United Kingdom (May).

Bell, R. M. (1990). Continuing industrialisation, climate change and international technology transfer. A report prepared in collaboration with the Resource Policy Group, Oslo, Norway. Science Policy Research Unit, University of Sussex, Falmer, Brighton, United Kingdom (December).

Brown, R. and P. Daniel (1991). Environmental issues in mining and petroleum contracts. IDS Bulletin, vol. 22, No. 4. Brighton, United Kingdom: University of Sussex, Institute of Development Studies (IDS).

Centro de Tecnología Mineral (1990). Analysis of garimpeiro in Brazil. Report of a research project. Rio de Janeiro, Brazil.

Chandler, M. (1983). The politics of provincial resource policy. In The Politics of Canadian Public Policy, M. Atkinson and M. Chandler, eds. Toronto: University of Toronto Press.

Cole, H. S. D., and others, eds. (1973). Thinking about the Future: A Critique of "Limits to Growth". London: Chatto and Windus.

Conway, T. (1990). Taking stock of the traditional regulatory approach. In Getting it Green: Case Studies in Canadian Environmental Regulation, G. Bruce Doern, ed. Toronto: C. D. Howe Institute.

Coppel, N. (1992). World-wide minerals and metals investment and the environment, 1980-1992. Unpublished report for Rio Tinto-Zinc (RTZ) Corporation, PLC (Public Limited Company) (August) London.

Cox, A. (1992). Mining, the environment and land access policy in Australia. Paper prepared for the John M. Olin Foundation Distinguished Lectureship Series in Mineral Economics. Golden, Colorado: Colorado School of Mines.

Crandall, R. W. (1983). Controlling Industrial Pollution. Washington, D.C.: Brookings Institute.

Crouch, D. (1990). Personal communication, McLaughlin Mine, California.

Crozier, R. D. (1990). Chile's legacy - pollution. Mining Journal (24 August).

Dales, J. H. (1968). Pollution, Property and Prices. Toronto: University of Toronto Press.

Downing, P. B. and L. J. White (1986). Innovation in pollution control. Journal of Environmental Economics and Management, vol. 13, pp. 18-29.

Eggert, R. G. (1989). Exploration and access to public lands. Resources Policy (June).

_____ (1992). Exploration. In Competitiveness in Metals: The Impact of Public Policy, J. J. Landsberg, M. J. Peck and J. E. Tilton, eds. London: Mining Journal Books.

United States, Environmental Protection Agency (1979). The Cost of Clean Air and Water. Report to Congress. Washington, D.C.: Environmental Protection Agency.

_____ (1986). Gregory tailings. Unpublished briefing paper, Washington, D.C. (July).

_____ (1989). Soil clean-up of Smuggler Mountain site. Unpublished briefing paper. Washington, D.C. (March).

Filion, M. P. and P. Ferguson (1990). Acid mine drainage research in Canada. Unpublished briefing paper, Canadian Centre for Mineral and Energy Technology and Environment Canada, Ottawa, Canada (April).

Freeman, C. (1992). Values, economic growth and the environment. Part III of C. Freeman, The Economics of Hope: Essays on Technical Change, Economic Growth and the Environment, London and New York: Pinter Publishers.

_____, and M. Jahoda, eds. (1978). World Futures. London: Martin Robertson.

Gana, J. (1991). U.S. environmental regulations and the mining industry. Paper prepared for the Centre for Copper and Mining Studies CESCO, Chile, and submitted as an unpublished working paper of the Mining and Environment research network, Science Policy Research Unit, University of Sussex, United Kingdom (September).

Gao, L., Z. Wenmin and Y. Xinhai (1993). Environmental management, technical innovation and sustainable development of the non-ferrous metal mines in China. Paper presented at the Third Annual Mining and Environment Research Network Workshop, Wiston House, Steyning, United Kingdom, 14-16 September 1993.

Gao, L., S. Zhiyou and Z. Wenmin (1992). Environmental management policies and reclamation of mine land in China. Paper presented at the Second Annual Mining and Environment Research Network Workshop, Wiston House, Steyning, United Kingdom, September 1992.

Graves, A. P. (1991). Globalisation of the automobile industry: the challenge for Europe. In Technology and the Future of Europe, C. Freeman, M. Sharp, W. Walker, eds. London: Pinter Publishers, pp. 261-282.

Gruenspecht, H. K., and L. B. Lave (1989). The economics of health, safety, and environmental regulation. In Handbook of Industrial Organisation, vol. II, R. Schmalensee and R. D. Willig, eds. Oxford: Elsevier, pp. 1,508-1,550.

Hahn, R. W. (1989). Economic prescriptions for environmental problems: how the patient followed the doctor's orders. Journal of Economic Perspectives, vol. 3, pp. 95-144.

Hanai, M. (1993). Industrial mining, "garimpos" gold prospectors and the environment in Brazil. Unpublished working paper of the Mining and Environment Research Network, Science Policy Research Unit, University of Sussex, United Kingdom (September).

Hoffman, S., and V. Houseman (1990). Update on regulations for mine waste management under RCRA. Mining Engineering (November), pp. 1,242-1,244.

Hollaway, J. (1993). Cyanide, mercury and the environment in southern and eastern Africa. Paper presented at the Third Annual Mining and Environment Research Network Workshop, Wiston House, Steyning, United Kingdom, 14-16 September 1993.

Huppes, G. (1988). New instruments for environmental policy: a perspective. International Journal of Social Economics, vol. 15, pp. 42-50.

Isnor, R. (1993). The relationship between environmental regulation and industrial innovation. Unpublished working paper of the Mining and Environment Research Network, Science Policy Research Unit, University of Sussex, United Kingdom (July).

Jacobs, M. (1991). The Green Economy - Environment, Sustainable Development and the Politics of the Future. London: Pluto Press.

Johnson, C. J. (1990). Ranking countries for mineral exploration. Natural Resources Forum, vol. 14, No. 3. (August), pp. 178-186.

Jordan, R., and A. Warhurst (1992). The Bolivian mining crisis. Resources Policy (March).

Kelly, D. R. (1990). Personal communication, Alcan International, Ltd., Montreal.

Kemp, R., and L. Soete (1990). Inside the "green box": on the economics of technological change and the environment. In New Explorations in the Economics of Technical Change, C. Freeman and L. Soete, eds. London: Pinter Publishers.

Kiernan, V. (1993). What am I bid for two tonnes of sulphur dioxide? New Scientist, vol. 138 (10 April), p. 10.

Kneese and Schultze (1978). Pollution, Prices and Public Policy. Washington, D.C.: The Brookings Institute.

Kopp, R. J., and V. K. Smith (1989). Benefit estimation goes to court: the case of natural resource damage assessments. Journal of Policy Analysis and Management, vol. 8, No. 4, pp. 593-612.

Krier, J. E., and E. Ursin (1979). Forcing technology: the clean air experience. Yale Law Journal, vol. 88, pp. 1,713-1,734.

Lagos, G., and P. Valesco (1992). Mining and the environment: the Chilean case. Unpublished working paper of the Mining and Environment Research Network, Science Policy Research Unit, University of Sussex, United Kingdom (March).

Loayza, F. (1993). Environmental management of mining firms in Bolivia: implications for environmental and industrial policies aiming at sustainable growth in low-income countries. Progress report. Mining and Environment Research Network, United Kingdom (July).

Lootens, D., and B. Kiernan (1990). Mining regulations: U.S. and Australia. Mining Journal Environment Supplement, vol. 314, No. 8,059, pp. 10-11.

MacDonnell, L. J., and A. Warhurst (1992). Environmental regulations. In Mining and the Environment - The Berlin Guidelines. London: Mining Journal Books.

Majone, G. (1976). Choice among policy instruments for pollution control. Policy Analysis, pp. 589-613.

Marcus, A. (1980). Environmental Protection Agency. In The Politics of Regulation, J. Q. Wilson, ed. New York: Basic Books.

Mauleg, D. A. (1989). Emission credit trading and the incentive to adopt new pollution abatement technology. Journal of Environmental Economics and Management, vol. 16, pp. 52-57.

Meadows, D. H., and others (1972). The Limits to Growth. London: Pan.

Milliman, S. R., and R. Prince (1989). Firm incentives to promote technological change in pollution control. Journal of Environmental Economics and Management, vol. 17, pp. 247-265.

Morgan, C. (1992). The privatisation of State industries - guidelines on environmental liabilities. Unpublished paper presented at the Second Annual Mining and Environment Research Network Workshop, Wiston House, Steyning, United Kingdom, 2-5 September 1992.

Moyan, P., W. G. Dallas and G. R. Ricks (1990). Is the Irish mining industry ready to meet the challenge. Mining Journal. (24 August), pp. 8-9.

Nuñez, A. (1992). Heterogeneity of production and domestic technological capabilities in mining and mining related productive and service activities in Peru: their relevance for an environmental strategy. Unpublished working paper of the Mining and Environment Research Network, Science Policy Research Unit, University of Sussex, United Kingdom (September).

_____ (1993). Environmental management in a heterogeneous mining industry: the case of Peru. Unpublished paper presented at the Third Annual Mining and Environment Research Network Workshop, Wiston House, Steyning, United Kingdom, 14-17 September 1993.

O'Connor, D. C. (1991). Market based incentives. In Environmental Degradation from Mining and Mineral Processing in Developing Countries: Corporate Responses and National Policies, A. Warhurst, ed. Discussion document, sect. 2, chap. 5, p. 189. Falmer, Brighton, United Kingdom: Science Policy Research Unit, University of Sussex.

OECD (1989). Economic Instruments for Environmental Protection, Paris: OECD.

_____ (1990). Environmental concerns related to commodities: scrap recovery and recycling of non-ferrous metals and environmental policy instruments: the 1989 Basel Convention. Unpublished briefing paper (Paris, 15 October).

_____ (1991). Environmental Policy: How to Apply Economic Instruments. Paris: OECD.

O'Riordan (1988). The politics of sustainability. In Sustainable Environmental Management: Principles and Practice, R. K. Turner, ed. London: Belhaven Press/Boulder, Colorado, Westview Press.

Orr, L. (1976). Incentives for innovation as the basis of effluent charge strategy. American Economic Review, vol. 56, pp. 441-447.

Panayotou, T., Q. Leepowpanth and D. Intarapravich (1990). Mining, environment and sustainable land use: meeting the challenge. Synthesis paper, No. 2, 1990 TDRI (Thailand Development Research Institute). Year-End Conference, Jomtien, 8 and 9 December 1990.

Pashigan, B. P. (1985). Environmental regulation: whose self-interests are being protected?. Economic Inquiry, vol. 23, pp. 551-584.

Pearce, D., A. Markandya and E. B. Barbier (1989). Blueprint for a Green Economy. London: Earthscan.

Pezzey, J. (1989). Economic Analysis of Sustainable Growth and Sustainable Development. Environment Department Working Paper, No. 15, Washington, D.C.: World Bank.

Probst, K. N., and P. R. Portney (1992). Assigning Liability for Superfund Cleanups: an Analysis of Policy Options. Washington, D.C.: Resources for the Future.

Redclift, M. (1987). Sustainable Development: Exploring the Contradictions, London: Methuen.

_____ (1993). Sustainable development: needs, values, rights. Environmental Values, vol. 2, No. 1 (Spring).

Richardson, O. (1993). Environmental policy-making and Ontario's mining industry. CRS Perspectives, vol. 45 (July/August), pp. 2-9. Kingston, Ontario, Canada: Centre for Resource Studies (CRS).

Ross, M. H., and R. H. Socolow (1991). Fulfilling the promise of environmental technology. Issues in Science and Technology (Spring) pp. 61-66.

Rothwell, R. (1981). Some indirect impacts of government regulation on industrial innovation in the United States. Technological Forecasting and Social Change, vol. 19, pp. 57-80.

_____ (1992). Industrial innovation and government environmental regulation: some lessons from the past. Technovation, vol. 12, No. 7, pp. 447-458.

Scales, M. (1991). Departing with dignity. Canadian Mining Journal, vol. 112 (May), pp. 33-37.

_____ (1992). Holding pattern. Canadian Mining Journal, vol. 113 (January), pp. 10-14.

Shannon, J. (1992). The Pollution Prevention Act of 1990: implementing its regulatory development provisions. Environmental Permitting, vol. 1 (autumn), pp. 453-458.

Skea, J. (1993). Environmental issues, In Handbook of Industrial Innovation M. Dodgson and R. Rothwell, eds., Forthcoming.

Stewart, R. B. (1975). The reformation of American administrative law. Harvard Law Review, vol. 88, pp. 1,667-1,813.

Tiffin, S., and F. Ostotimehin (1992). New Technologies and Enterprise Development in Africa. Development Centre Studies. Paris: OECD.

Tilton, J. E. (1992). Mining waste, the Polluter Pays Principle and US Environmental Policy. Boulder, Colorado: Colorado School of Mines, Department of Mineral Economics Working Paper No. 92-8 (October).

Turner, R. K. (1988). Sustainability, resource conservation and pollution control: an overview. In R. K. Turner, Sustainable Environmental Management: Principles and Practice, London: Belhaven Press.

United States Department of the Interior, Bureau of Mines (1989). Bauxite, Alumina, Aluminium Annual Report. Washington, D.C.: US Government Printing Office.

Warhurst, A. (1990). Employment and Environmental Implications of Metals Biotechnology. World Employment Programme Research Working Paper. Geneva: International Labour Organisation (ILO). WEP 2-22/SP.207 (March).

_____ (1991a). Metals biotechnology for developing countries and case studies from the Andean Group, Chile and Canada. Resources Policy (March), pp. 54-68.

_____ (1991b). Technology transfer and the development of China's offshore oil industry. World Development, vol. 19, No. 8, pp. 1,055-1,073.

_____ (1992a). Environmental management in mining and mineral processing in developing countries. Natural Resources Forum (February).

_____ (1992b). Environmental management. In Mining and the Environment: the Berlin Guidelines, chap. 7. London: Mining Journal Books.

_____ (1992c). The limitations of environmental regulation: an argument for technology policy to promote environmental management in mining. Paper prepared for the 1992 John M. Olin Distinguished Lectureship Series in Mineral Economics. Golden, Colorado: Colorado School of Mines. (November). To be published in R. Eggert, ed. Perspectives on Public Policy Toward Mining and the Environment. Washington, D.C.: Resources for the Future.

_____ Environmental Degradation from Mining and Mineral Processing in Developing Countries: Corporate Responses and National Policies. Paris: OECD Development Centre. Forthcoming.

Whiteway, P., ed. (1990). Who's on first. Canadian Mining Journal, vol. 111 (December), pp. 14-18.

Whitlock, J. L., and T. I. Mudder (1989). The Homestake Wastewater Treatment Process: biological removal of toxic parameters from cyanidation wastewaters and bioassay effluent evaluation. Homestake internal working paper. San Francisco, California: Homestake Mineral Development Company.

Wilson, J. Q. (1980). The Politics of Regulation. New York: Basic Books.

Winters, R., and L. Marshall (1991). Where's the Recovery in Resource Conservation and Recovery Act (RCRA): the Re-mining of Non-Coal Abandoned Mine Sites. Proceedings of the Twelfth Annual Meeting of the National Association of Abandoned Mine Land Programs, 9-10 September 1991.

Womack, J., D. I. Jones and D. Roos (1990). The Machine that Changed the World, New York: Macmillan.

World Commission on Environment and Development (1987). Our Common Future, Oxford and New York: Oxford University Press.